Thesis
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THE DEVELOPMENT OF TILAPIA FEEDS BASED ON LOCALLY AVAILABLE MATERIALS IN ZAMBIA.

By

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A thesis submitted to the University of Stirling for the degree of Doctor of Philosophy.

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DECLARATION

I hereby declare that the research work presented in this thesis was conducted by me and that this work has never been submitted for any other degree.

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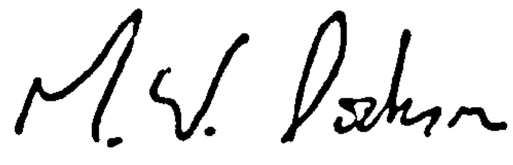

Malcolm William Dickson

June 1989.

This thesis is dedicated to my wife, Cathryn, son, Iain and the workers and staff at the Nakambala Estate of the Zambia Sugar Company.

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ABSTRACT.

Nakambala Tilapia Farm commenced operations at the Nakambala Estate of the Zambia Sugar Company near Mazabuka, Zambia in early 1982. The farm used an intensive tank system designed to produce 50 tonnes of tilapias per annum to provide fish for feeding the labour force on the sugar estate. The project had to manufacture fish feeds on site. A wide range of feed raw materials were used over the course of the project, with formulations designed to aim to supply the nutrient levels suggested by the University of Stirling, Institute of Aquaculture. The raw materials included microalgae from a pilot scale algae culture project funded by the Overseas Development Administration, dried fish, blood meal, carcase meal, soyabeans, cottonseed, hydrolysed feather meal, sunflower oilcake, lucerne, leucaena, yeast, wheatings and maize. This involved identification of raw material supplies, development of appropriate feed processing methods, formulation of feeds and manufacture of the feeds. Seventeen feed trials were carried out to evaluate the use of different feed formulations. Many of these trials concentrated on the supply of vitamins in the feeds as the provision of a vitamin supplement was made impossible by restrictions on foreign exchange allocations.

The main conclusions were:

1. The poor financial performance of the farm in the initial years of operation was due to problems in project implementation, particularly the absence at the start of the project of a breeding population of tilapias of a species with proven growth potential in an intensive system.

2. The feeds being produced by 1985 were adequate to sustain good growth in tilapias. Feed trials had shown that there was no need to use a vitamin supplement in the feeds despite advice to the contrary from other authorities.

3. The farming system utilised was appropriate to Zambian conditions, despite being extremely intensive.

CHAPTER 1 TILAPIA FARMING AND FEED REQUIREMENTS.

1.1. Farming methods for tilapias and the feed requirements of different systems.

Tilapia farming is carried out using a variety of different methods. Table 1 summarises the requirements and features of some examples. In the least intensive systems, fish are stocked into a water body and recovered after a period of time. No attempt is made to provide any additional feed for the fish beyond the natural feed such as algae, bacteria and invertebrates which are already in the water body. Fish production depends principally on the relationship between the quantity and quality of natural food in the water body or pond and the biomass of fish. If the fish use up or outgrow the natural food resources, they will starve. Production rates vary from 0 - 2 tonnes of fish/hectare/annum depending on the precise conditions (Balarin and Hatton, 1979) and water usage need only replace what is lost through seepage and evaporation.

This type of farming system may appear to be attractive as it can often be carried out in existing facilities such as irrigation dams and requires only juvenile fish with which to stock the ponds and a means of catching the fish at harvest, such as a seine net. There are, however, a number of problems common to most pond systems when farming tilapias:

(i) Most species of tilapias, when given a restricted food supply and plenty of room in a mixed sex culture, will tend to reproduce rather than grow. The fish can mature at sizes as small as 8 - 9 cm producing, at harvest, a large number of very small fish of low market value rather than the relatively few, large fish intended at the time of stocking (Macintosh and Sampson, 1985). A number of approaches have been developed to circumvent this problem in pond culture including the use of predator fish to reduce the numbers of suviving fry (Huet, 1972) and the use of single sex

Table 1. Examples of Tilapia Culture Systems.

	Extensive			Intensive
	Stocked Reservoirs	Fertilised Fish Ponds	Fertilised and Fed Ponds	Tank Culture
Production	0-3t/ha/yr	3-8t/ha/yr	4-20t/ha/yr	2000t/ha/yr or 200kg/m3/yr
Feed	None	None	Supplemental Feed	Complete Feed
Water Supply	Replace Evaporation	Replace Evaporation	Replace Evaporation	Min. 0.1 l/min/kg of Fish Stocked
Soil Type	Non-porous	Non-porous	Non-porous	Not important
Aeration	No	No	At Times	Continual
Security	Poor	Poor	Poor	Good

Examples of the systems described:

1. Stocked Reservoir: Mubuyu Farm, nr. Mazabuka, Zambia.- a mixed farm which utilises water storage dams to irrigate crops in the dry season.

2. Fertilised Fish Ponds: Kafue Fisheries Ltd., Kafue, Zambia. - a combined fish and pig farm where the droppings of the pigs are used to fertilise the fish ponds.

3. Fertilised and Fed Fish Ponds: Israeli fish ponds.

4. Intensive Tanks: Nakambala Tilapia Farm.

cultures achieved by hormone treatment of the fish (Guerrero, 1975), by hand sexing of the fish prior to stocking in the ponds, or by hybridisation of particular species which tend to produce a high proportion of males (Balarin and Hatton, 1979).

(ii) If the ponds are not capable of being fully drained before stocking, it is likely that cannibalistic fish may be present at stocking resulting in stock losses which may not become apparent until the time of harvest.

(iii) Due to the large area of water used, it can be difficult to prevent theft of fish and exclude predators such as piscivorous birds and mammals.

The easiest way to improve the productivity of a pond system for tilapia culture is by the addition of organic or inorganic fertilisers. The fertilisers used range from inorganic mixes of nitrogen, phosphorous and potassium used in conventional agriculture, through to animal wastes such effluent from intensive cattle or pig rearing enterprises and food production byproducts such as coffee processing wastes and sugar cane bagasse (Kohler and Pagan-Font, 1978). The principal effect of the fertilisers is to increase the growth of algae and bacteria in the ponds, some of which is ingested directly by the fish, the remainder enhances the growth of invertebrates which are subsequently eaten by the fish. Some organic wastes such as manures may be eaten directly by the fish. Fertilised pond systems are widely used. Fish production rates depend on the type of fertiliser used, the stocking rate of fish, the species of fish and other environmental factors, however yields of 2.5 - 6 tonnes/hectare/annum are usual and yields as high as 20 tonnes/hectare/annum have been quoted (Flynn, personal communication ; Edwards *et al* 1981).

Further production increases can be achieved in a pond system by the addition of supplementary feed. It is termed supplementary because it is used to augment the natural feeding due to natural pond productivity or pond fertilisation. The feed need not aim to supply the complete range of nutrients required by tilapias as the natural

food in the pond contains higher levels of protein and vitamins than are required by the fish (Sarig, personal communication). Supplementary foods can range from simple applications of agricultural byproducts such as rice bran (Msiska, 1983) to formulated pellets supplying moderate amounts of protein (15 - 25%) and large amounts of energy. Fish production rates using these methods range from 4 - 20 tonnes/hectare/annum (Sarig and Arieli, 1980).

The next limitation to the productivity of a pond system is the diurnal oxygen fluctuations which result from the photosynthetic and respiratory activities of algae in the ponds. During daylight hours, algae photosynthesise, producing oxygen and consuming carbon dioxide. During the night algae consume oxygen by respiration and, along with the oxygen demands of the fish, bacteria and other organisms in the pond, can cause a critical shortage of oxygen. If the oxygen level falls below the lower lethal oxygen requirement of the tilapias (0.1 - 1 mg/l [Balarin and Hatton, 1979]), the fish will die. If the oxygen level falls to zero, all pond life, including the algae, will die. This can be avoided by aeration or oxygenation of the ponds during the critical periods.

Further intensification of tilapia culture can be achieved by the use of "clean water" systems. In these, no attempt is made to produce natural food for the fish and they derive all their nutrition from a complete feed formulated to supply all the nutrients required for growth and maintainence.There are three main types of intensive system in operation:

(i) Intensive ponds. This type of pond system is different from those describedabove because a high flowthrough of water is used to supply the oxygen demands of the fish. This means that natural food cannot be cultivated in the pond and a complete feed must be supplied. Israeli research has shown that yields of up to 36 tonnes/hectare/annum can be achieved (Rappaport and Sarig, 1975).

(ii) Cage culture.The fish are suspended in an enclosed net or cage, usually in a relatively large water body. The oxygen requirements of the fish are supplied by the flow of water through the mesh walls of the cage and fish faeces fall through the bottom of the cage. Although this has developed as a way of growing tilapias in fertilised ponds with or without supplementary feeding (Beveridge, 1987), it has also been used in clean water systems with production rates as high as 200kg/m^3/annum (Coche, 1977).

(iii) Intensive tank culture. In this form of tilapia culture, the fish are held in tanks, usually made of concrete or fibreglass. The tanks may be round, square or rectangular but the essential feature is that they are designed to be self ceaning, that is, there is no build up of faeces or uneaten food on the bottom of the tank in normal use. This is achieved by creating a flow, either through directing the inflow of water or using directional flow aerators, which carries particulate waste to the outlet screen of the tank. Very high stocking densities can be achieved (up to 100 kg/m^3) resulting in production rates of up to 200kg/m^3/annum (Zohar, Rappaport and Sarig, 1985; Balarin and Haller, 1982; Hough, internal Tate and Lyle report).

The major advantage which these very intensive systems have over the more extensive systems is that the high stocking densities utilised disturb the normal breeding behaviour of tilapias. This delays the onset of maturity and allows fish growth to carry on at predictable rates and to sizes which are easily marketed (Allison *et al*/1976). Another advantage of intensive systems is that the area of land required is small so it is easier to protect the stock from predation or theft. The site conditions are, however , fairly specific. Intensive ponds or tanks require 0.1 - 1 litre of clean water per minute for each kilogramme of fish on the farm, with sufficient head of pressure for the water to flow through the tanks under gravity. Intensive cages need a site with deep, relatively sheltered, water.

The other major factor which must be considered if tilapia culture is to be carried out at a particular site is the availability of complete feeds.In developing countries such as Zambia, it is this factor which often precludes consideration of intensive culture. A complete feed must supply all the nutrients required for growth. These requirements are summarised in Section 1.2. Some of these nutrients, in particular the high quality proteins and the micronutrients, are often unavailable from sources within a developing country and so must be imported. Foreign exchange shortages can make this difficult or at times impossible, making the consistent production of complete feeds based on conventional formulations impossible.

The fish farm project at Nakambala was planned with the knowledge that complete feeds would have to be produced entirely from locally available ingredients as the tilapia farming system chosen was very intensive.

1.2. Review of Tilapia feed requirements.

Many papers have been published in recent years on different aspects of tilapia nutrition. The subject is broad because the tribe tilapinil (tilapias) comprise many different species, often with quite different natural feeding preferences and the method of farming varies widely from study to study. This review will concentrate on studies carried out using intensive farming systems requiring the feeding of complete feeds, as this was the method of nutrition used at the Nakambala Tilapia Farm. Jauncey and Ross (1982) and Jauncey and Ross (in press) have given more complete reviews of tilapia nutrition.

The main nutrients required for the growth of tilapias are Protein, Lipids, Carbohydrates Vitamins and Minerals.

(i) Protein.

Proteins are often referred to as the building blocks of animal nutrition because they form the basic structures of animal cells, muscles and connective tissue as well as being central to many of the physiological reactions in an animal. Proteins are complicated molecules consisting of chains of subunits called amino acids. All non ruminant animals require a constant supply of dietary amino acids to replace those broken down from existing tissues and for growth. Most of the 25 commonly occurring amino acids, do not need to be supplied in the exact form in which they are to be utilised, but can be synthesised from other amino acids. Ten of the amino acids cannot be synthesised in this way and are termed essential amino acids, that is they must be supplied in the exact form and quantity in which they are required by the

animal, if growth, maintainence or reproduction are not to be affected. Because of this central role in animal nutrition and the relative expense of high protein feed ingredients, the provision of the correct quantity and quality of protein is usually the first priority in an aquaculture feed. If the balance of essential amino acids is not correct, or there is insufficient energy in the diet from fats or carbohydrates, proteins in fish diets will be broken down to supply energy. This form of energy production is wasteful as energy can usually be supplied more cheaply from fats or carbohydrates.

The quantity of protein required by tilapias has been estimated in many studies. It depends principally on the size of the fish, smaller fish requiring higher levels of protein in the diet to produce optimal growth. Jauncey (1982) showed the optimum protein requirement of *Oreochromis mossambicus* juveniles (1 - 10g average weight) to be 40% of the diet. Ross (1982) showed that for larger fish the optimum was around 30% reducing to 25% for *O. mossambicus* over 30g. Viola and Zohar (1984) in more production orientated trials seemed to show a seasonal effect in the requirement for protein. With large fish (100g+), 30% and 35% protein diets performed better in the Summer than 25% protein diets whereas in Spring there was no significant difference. Teshima, Kanazawa and Uchiyama (1985) demonstrated that 0.5g+ *Oreochromis niloticus* juveniles grew best on a feed containing 35% protein.

The other major factor regarding protein nutrition is the quality of the protein or its amino acid content. Although the optimal dietary levels of amino acids have been established for many species of fish, the requirements for tilapias have still not been well established. Jackson and Capper (1982) indicated minimum dietary requirements of 0.53% methionine (at a dietary level of 0.74% Cystine) and 1.62% Lysine for *O. mossambicus* juveniles, whilst similar tests for arginine requirements were

inconclusive. Jauncey, Tacon and Jackson (1983) encountered considerable difficulty in adapting tilapias to the standard type of synthetic test diets used in these studies and expressed doubts about the ability of tilapias to utilise supplies of free amino acids in such diets. Some studies have shown that amino acid supplementation of diets can be effective. Shiau, Chuang and Sun (1987) found that methionine supplementation of a diet containing soyabeans for juvenile *Oreochromis niloticus/Oreochromis aureus* hybrids increased growth in fish fed a 32% protein diet but not in those fed a 24% protein diet. With the scarcity of information on the amino acid requirements of tilapias, recommendations are generally taken from other fish species, from the deposition rates of amino acids in fish tissues and from the amino acid composition of tilapia tissues (Ogino, 1980; Jauncey, Tacon and Jackson, 1983). The current recommendations given by the University of Stirling, Institute of Aquaculture, Unit of Fish Nutrition are shown in Table 2. A recent study by Santiago and Lovell (1988) using *O. niloticus* fry fed test diets in feeding experiments, indicated that optimum essential amino acid levels were significantly higher than those recommended by the University of Stirling. However the experiments were carried out using very small fish (start weights 15 - 87mg) fed diets with sub - optimal protein levels (28%) with no indication of the efficiency of feed utilisation. There is no guarantee that these results could be transferred to larger fish where feed costs are more economically significant.

(ii) Lipids

The two main functions for lipids in animal nutrition are to provide energy and as a source of essential fatty acids.

Lipids contain higher levels of energy than any of the other energy containing components of foodstuffs. Lipids contain 9.4 kcal/g total energy compared to 5.6 kcal/g for protein and 4.1 kcal/g for carbohydrates (White *et al* 1964). They are

Table 2. Recommended nutrient levels in feeds for Tilapias in intensive culture (Jauncey, pers. comm).

	Fish Size				
Nutrient	<0.5g	0.5 - 10g	10 - 35g	35g +	Broodstock
Crude Protein [1]	50%	35 - 40%	30 - 35%	25 - 30%	30%
Crude Lipid [2]	10%	10%	6 - 10%	6%	8%
Carbohydrate	25%	25%	25%	25%	25%
Fibre	8%	8%	8 - 10%	8 - 10%	8 - 10%

1. Crude Protein containing essential amino acids as follows(Expressed as %age of protein content): Arginine 2.8%, Histidine 1.1%, Isoleucine 2.0%, Leucine 3.4%, Lysine 3.8%, Methionine 1.0 %, Phenylalanine 2.5%, Threonine 2.9%, Tyrosine 0.4%, Valine 2.2%.

2. Crude Lipid containing 1% n-3 and 1% n-6 essential fatty acids as %age of the diet.

The feed should also contain a vitamin and mineral premix.

Vitamin premix: Vitamin A 200000 IU/kg, Vitamin D3 1000000 IU/kg, Vitamin E 10000 IU/kg, Vitamin K 1000 mg/kg, Vitamin B1 1000 mg/kg, Vitamin B2 2000 mg/kg, Vitamin B6 1000 mg/kg, Vitamin B12 100 mg/kg, Nicotinic Acid 2800 mg/kg, Pantothenic acid 2500 mg/kg, Choline chloride 50000 mg/kg, Vitamin C 125000 mg/kg, Folic acid 600 mg/kg, Biotin 100 mg/kg, Inositol 20000 mg/kg, Antioxidant 20000 mg/kg.

Mineral premix: Calcium orthophosphate 728 g/kg, Magnesium sulphate 127 g/kg, Sodium chloride 60 g/kg, Potassium chloride 50 g/kg, Iron sulphate 25 g/kg, Zinc sulphate 5.5 g/kg, Manganese sulphate 2.5 g/kg, Copper sulphate 0.8 g/kg, Cobalt sulphate 0.5 g/kg, Calcium iodate 0.3 g/kg, Chromic chloride 0.13 g/kg.

The vitamin premix should be included at 1%(10kg/tonne of feed) and the mineral premix at 4%(40kg/tonne of feed).

therefore an efficient means of supplying energy in tilapia feeds. Stickney and Wurtz (1986) demonstrated increased growth in *O. aureus* with increasing dietary lipid levels up to 10%. Practically the limitations on the use of lipids as energy sources in tilapia feeds are that levels above 12% in the diet have been shown to cause depressed growth and accumulation of carcase lipids,(Jauncey and Ross, unpublished data) and feeds containing more than 10% lipid are difficult to mill and pellet using conventional pelleting techniques (Stickney, 1979). Higher levels of dietary lipids can be achieved by spraying the lipids onto the feed after pelleting, or by using extrusion processing as is used in current "high energy" feeds for salmonids.

One of the most common forms of lipid in animal nutrition is as triglycerides. Each triglyceride is composed of a glycerol molecule attached to three fatty acids. The fatty acids can vary in length from one to 22 carbon atoms and the bonds between the carbon atoms can be single bonds (saturated) or one or more of the bonds may be double bonds (unsaturated or polyunsaturated). Two classes of unsaturated fatty acids have been shown to be essential for the maintainence and growth of most animals, including fish. These are referred to as n-3 and n-6 fatty acids. The n-number refers to the relative positions of double bonds in the fatty acids. Most homiothermic animals have been shown to have a dietary requirement for n-6 polyunsaturated fatty acids, whereas most fish species require only essential fatty acids of the n-3 type (Cowey and Sargent, 1977). In contrast to this Kanazawa *et al* (1983) demonstrated that *Tilapia zilli* required a dietary supply of 1% n-6 fatty acid and Stickney and Wurtz (1986) suggested that dietary levels of linolenic acid (an n-3 fatty acid) over 1% depressed growth in *O. aureus*. It has been suggested that the difference between tilapias and most other fish studied to date, is due to the fact that most of the other species studied have been coldwater species. It may be that the greater degree of unsaturation of the n-3 fatty acids are necessary to maintain membrane phospholipid fluidity at the low

metabolic temperatures encountered in coldwater fish. The metabolism of warmwater fish such as tilapias and homiothermic animals is carried out at higher temperatures, at which the n-6 fatty acids would be sufficiently flexible (N.R.C., 1983).

(iii) Carbohydrates.

Carbohydrates consist of basic units containing only carbon, hydrogen and oxygen called monosaccharides. Each monosaccharide contains between three and six carbon atoms and they are joined together in chains to form sugars (up to ten monosaccharides) or polysaccharides (more than ten monosaccharides). For tilapia nutrition, carbohydrates can be divided into two classes, digestible carbohydrate and indigestible carbohydrate or fibre.

Digestible carbohydrates such as most starches and sugars can provide useful amounts of energy in tilapia feeds (Teshima *et al* 1985). They are not essential in the same way as some of the protein and lipid constituents, however the low cost of high carbohydrate raw materials such as cereals means that they are usually the cheapest energy source available (Jauncey and Ross, 1982).

Fibre is usually regarded as indigestible hence it does not supply energy to the fish (Jauncey and Ross, 1982). High levels have been shown to be undesirable in other species (Leary and Lovell, 1975) and it may affect the digestion of other nutrients.

As high carbohydrate ingredients often make up a large proportion of the total ingredients in tilapia feeds, they can have a profound influence on the consistency of the feed, affecting pellet hardness, density and water stability. Viola *et al* (1985) used

feeds containing a variety of high carbohydrate materials in trials with tilapias in intensive ponds. They found that despite the differences in pellet consistency between the different grains, fish growth was related more to the nutritive value of the grains than pellet stability.

(iv) Vitamins

Vitamins are organic compounds which are required in trace amounts for the normal functioning of animals, but which some animals are unable to synthesise. They are a diverse range of compounds but are usually divided into the water soluble vitamins (vitamin B1, vitamin B2, vitamin B6, pantothenic acid, niacin, biotin, folic acid, vitamin B12, choline, inositol, vitamin C) and the fat soluble vitamins (vitamin A, vitamin D, vitamin E, vitamin K). The principal difference between these two groups is that the fat soluble vitamins can be stored in animal tissues and the water soluble vitamins cannot. This means that it should be easier to demonstrate the effects of dietary deficiency of water soluble vitamins than fat soluble because an animal requires a constant supply of water soluble vitamins whereas it can cope with intermittent or fluctuating supplies of fat soluble vitamins.

Although requirements for specific vitamins have been demonstrated in other fish species (Halver, 1979), the only outright dietary vitamin requirement demonstrated so far in tilapias, has been for vitamin C. Work at the University of Stirling has demonstrated that relatively high levels of vitamin C (1250mg/kg of feed) are required in feeds for *O. niloticus* and *O. mossambicus* (Jauncey, Soliman and Roberts, 1985; Soliman, Jauncey and Roberts, 1986(a); Soliman, Jauncey and Roberts, 1986(b)).

Recommendations for inclusion levels of other vitamins in tilapia feeds (see table 2) are based mainly on information from other fish species.

(v) Minerals

There is very little information available on the mineral nutrition of fish (Tacon and De Silva, 1983; Lall, 1979). Recommendations for tilapias are usually based on those for other fish species. Watanabe *et al* (1980) postulated a dietary requirement for phosphorus of less than 0.9% in *O. niloticus* as supplementation of a basal diet containing this level did not result in improved growth. Robinson *et al* (1984) suggested that a dietary calcium level of 0.65% was adequate for *O. aureus* reared in calcium free water, although in most situations fish derive adequate supplies of calcium from the water (Nose and Arai, 1976).

The recommendations given for the nutrient requirements of tilapias by the University of Stirling are shown in Table 2. These were the targets aimed at when formulating feeds at Nakambala tilapia farm.

CHAPTER 2 CONSTRUCTION, LAYOUT AND OPERATION OF NAKAMBALA TILAPIA FARM.

2.1 Background.

The Nakambala Estate of the Zambia Sugar Company (Z.S.C) is near Mazabuka on the Kafue floodplain about 130 kilometres South West of Lusaka. The estate covers around 10000 hectares and produces from 70000 to 140000 tonnes of sugar per annum. All the sugar cane is cut by hand during the dry season which usually runs from April to November. Most of the 2-3000 cane cutters are not resident in the Mazabuka area but are from the Lozi tribe of the Western Province of Zambia. At the start of crop they are recruited in Western Province and are accommodated during crop in bunkhouses on the estate. They are provided with meals from the estate kitchens. Before the fish farm started, the main meal of lunch usually consisted of various beef and bean stews along with "nshima"(boiled maize). It had always been company policy to use produce which could be grown on the estate in the meals. Maize and beans were grown for this purpose. This was preferable to buying in ingredients because it gave the estate better control over the supply in times when there might be a national shortage of particular commodities.

There were sixteen irrigation dams on the estate which were occasionally netted and the fish used in the kitchens. Annual total yields were under one tonne per annum, but the fish was greatly appreciated by the estate workers. In the late 1970's the Zambia Sugar Company planned to start a fish farm to supply fish for the estate kitchens. The original plans were for an extensive system supplied by water from an irrigation canal at the edge of the sugar estate but concern was expressed about the potential difficulty of preventing theft from such a farm. The proposed site was close to the Kafue River and also close to a village of fishermen who were squatting on Zambia Sugar

Company land. The fishermen would have had both the equipment to catch, and connections with marketeers to sell, fish making any development close to the village very vulnerable to theft. The proposal was presented at a time when the estate had experienced serious problems with theft of crops, particularly maize, bananas and pineapples, resulting in the abandonment of growing bananas and pineapples.

Since the mid 1960's when the sugar estate was built, it had been managed under contract by Tate and Lyle, who supplied or recruited most of the senior management. In the late 1970's Tate and Lyle Technical Services (T.L.T.S.) had begun to develop an interest in aquaculture, firstly of algae as raw materials for chemical production, and subsequently of finfish, particularly tilapias. The main development was an intensive tilapia farm sited at the Tihange Nuclear Power Station near Liege in Belgium. The farm produced 50 tonnes/annum of *O. niloticus* in the cooling water effluent of the power station passed through ten D - ended tanks. Mixing of power station water with ambient temperature water and occasional recycling of water allowed temperatures to be maintained at 20 - 28°C. The project demonstrated that tilapias could be grown in intensive culture at densities of up to 100 kg/m^3 (Melard and Philippart, 1980; Delcambe-Fontaine, 1979; Hough, personal communication). As a result of the success of this project, the technology was offered by T.L.T.S. to sugar estates in the tropics in which they had interests. The idea was taken up by Z.S.C. in early 1981 and construction was scheduled to commence in late 1981. The project was to be wholly funded by Z.S.C.

The Nakambala Estate was deemed to be suitable for such a project because:

(i) There was a plentiful supply of water which could be piped to the farm under pressure. Nakambala Estate pumps up to 50000 m^3 /hr of water out of the Kafue River for irrigation of the sugar cane, operation of the sugar factory and provision of drinking water on the estate and in Mazabuka. The quantity of water required for the

fish farm was approximately 300m^3/hr which was insignificant compared to the total amount used on the estate.

(ii) There was a ready market for the fish, the estate kitchens.

(iii) The water temperatures were generally suitable for tilapia culture (see section 2.2). During Winter when temperatures fell below the optimum for growth, it was proposed to use low grade waste heat from the sugar factory to raise farm water temperatures.

(iv) Although the proposed farming system was very intensive, requiring a high level of management skill and technical backup, it was felt that this could be provided on a sugar estate, the operation of which also requires skilled management and technical facilities such as laboratories and workshops.

(v) The system could be relatively easily protected from theft as the small area of the farm could be contained within the factory security zone.

The main problem areas forseen at the start of the project were:

(i) The suitability of local fish species for intensive culture had not been tested. It was proposed to import two exotic species, *Oreochromis niloticus* and *Oreochromis aureus*, in case the local species proved to be unsuitable.

(ii) The provision of suitable feeds. The project was to include feed processing machinery and it was hoped that sufficient supplies of raw materials could be found within Zambia. In particular it was clear that there would be difficulty in providing protein for the feeds. It was proposed that this could be derived from fish caught in the irrigation dams and from algal culture using fish farm effluent as a substrate. This approach gained support from the Overseas Development Administration of the British Government who agreed to fund a three year research programme into algal culture at Nakambala. This research programme is described in Chapter 6.

2.2 Development Programme.

Figure 1 shows the proposed and actual development programmes for the project. As can be seen the project started later than anticipated, at the start of 1982 rather than in the middle of 1981. this was because of delays in making decisions within the Zambia Sugar Company and in approval of work permits for Tate and Lyle personnel. This meant that the project started in the rainy season which delayed construction of the hatchery. Water temperatures at Nakambala ranged from extremes of 28°C in Summer to 17°C in Winter. Figure 2 shows the average temperatures for each month over 5 years at the Hatchery. Tilapias breed at temperatures between 20 - 23°C (Balarin and Hatton, 1979), which meant that breeding at ambient temperatures at Nakambala was restricted to a season running from October to May. The delay in construction of the Hatchery meant that no breeding could take place before the 1982 Winter started, so breeding was delayed until October 1982. A six month delay in project implementation resulted in a twelve month delay in the breeding and production programme. Ordering and shipping of the equipment did not take much longer than planned despite some of the containers "disappearing" for a period on the Tazara railway between Dar es Salaam, in Tanzania, and Zambia.

Figure 1. Proposed and actual development programmes for the project

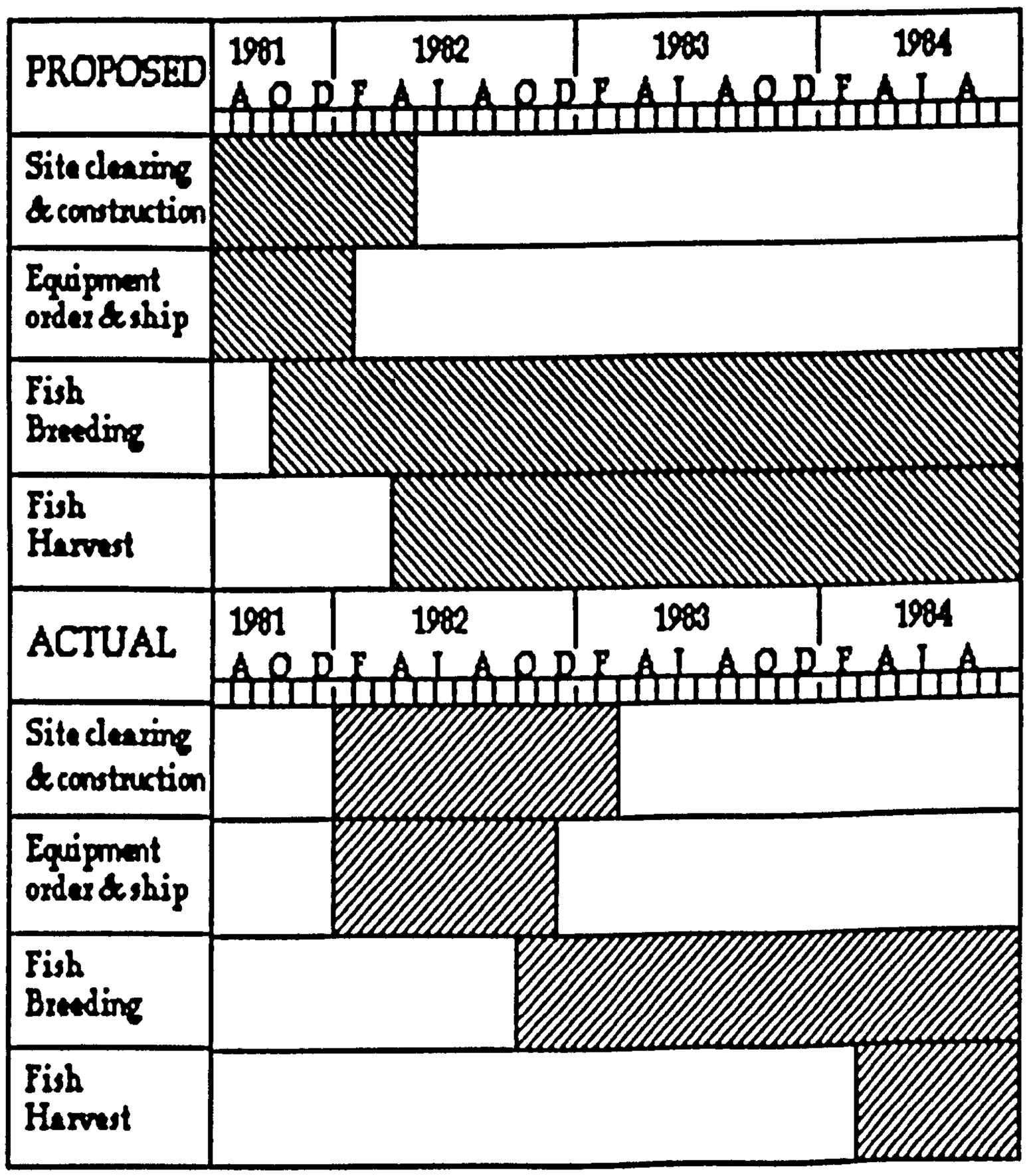
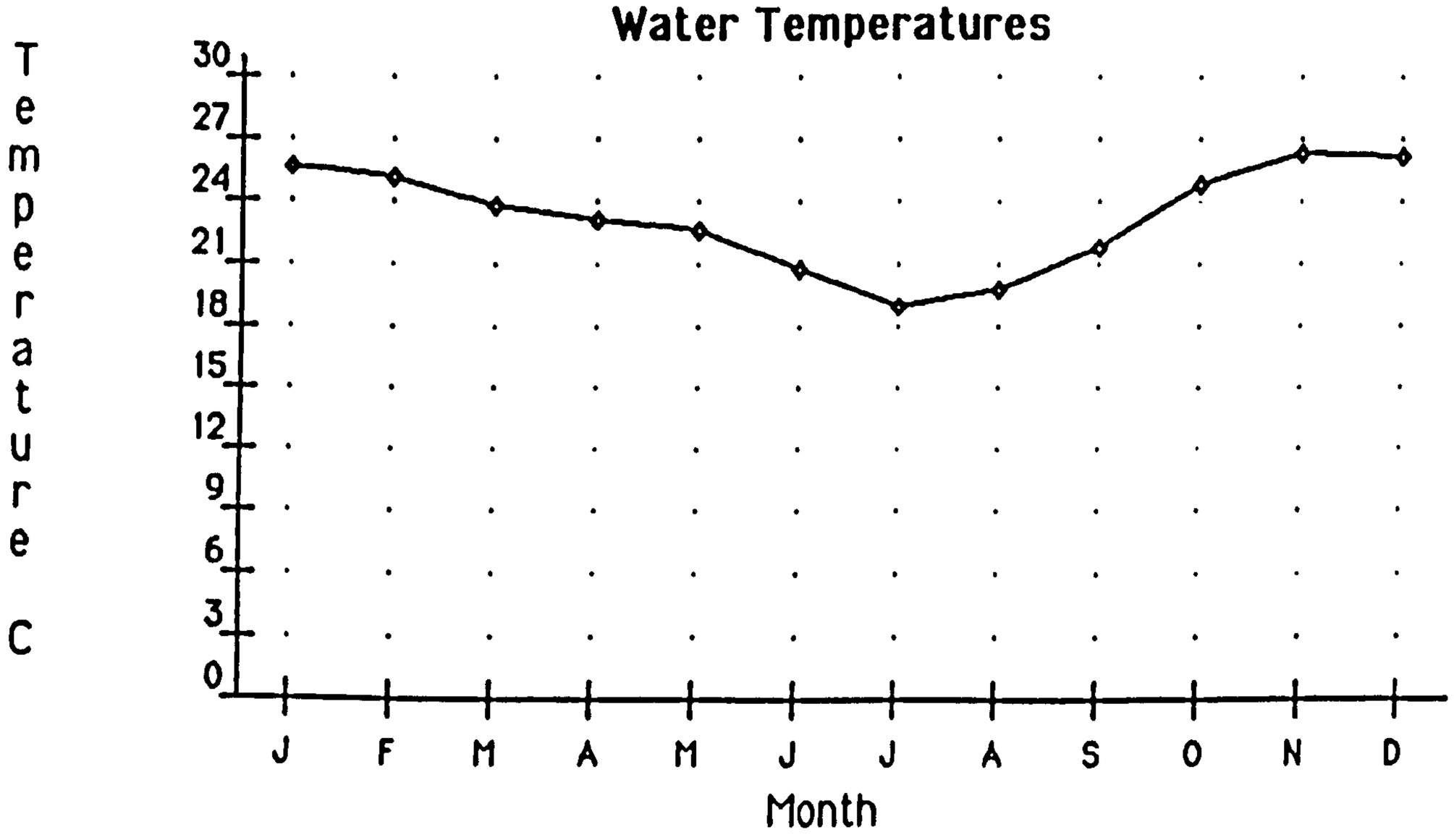


Figure 2. Ambient water temperatures at Nakambala Estate.

(Derived from the averages of readings taken at the Hatchery 1982-1986)



2.3. Farm layout.

Two sites were developed. Figure 3 shows site A, the Hatchery. The main water supply was by gravity through two siphons drawing water from an irrigation dam. Before construction the area was very swampy. The tanks were all made of plastered concrete brick walls and cast concrete bottoms. Excavation of the tank bases was by hand. The spoil from excavation was used to build up the overall site level. This combined with drainage gave a good working surface between the tanks over which light vehicles could be driven. The characteristics of each set of tanks including the approximate water flow through rates used are described in Table 3.

Most of the construction was completed before the arrival of imported equipment so the materials used had to be found locally. Heavy pipework and valves were salvaged from the factory scrapyard. Other pipework was generally of galvanised steel apart from the D-ended tanks which used locally sourced plastic pipes and fittings.

In late 1982 a borehole was sunk at the Hatchery site as a reserve water supply. This provided approximately 5 m^3/hr of water which was usually used to supply the arena and breeding pond. Borehole water had fairly constant temperatures(24 - 25°C), compared to dam water(17 - 28°C).

Four different types of fry production pond were constructed over the course of the project as shown in Figure 4:

Figure 3. Site layout at the hatchery.

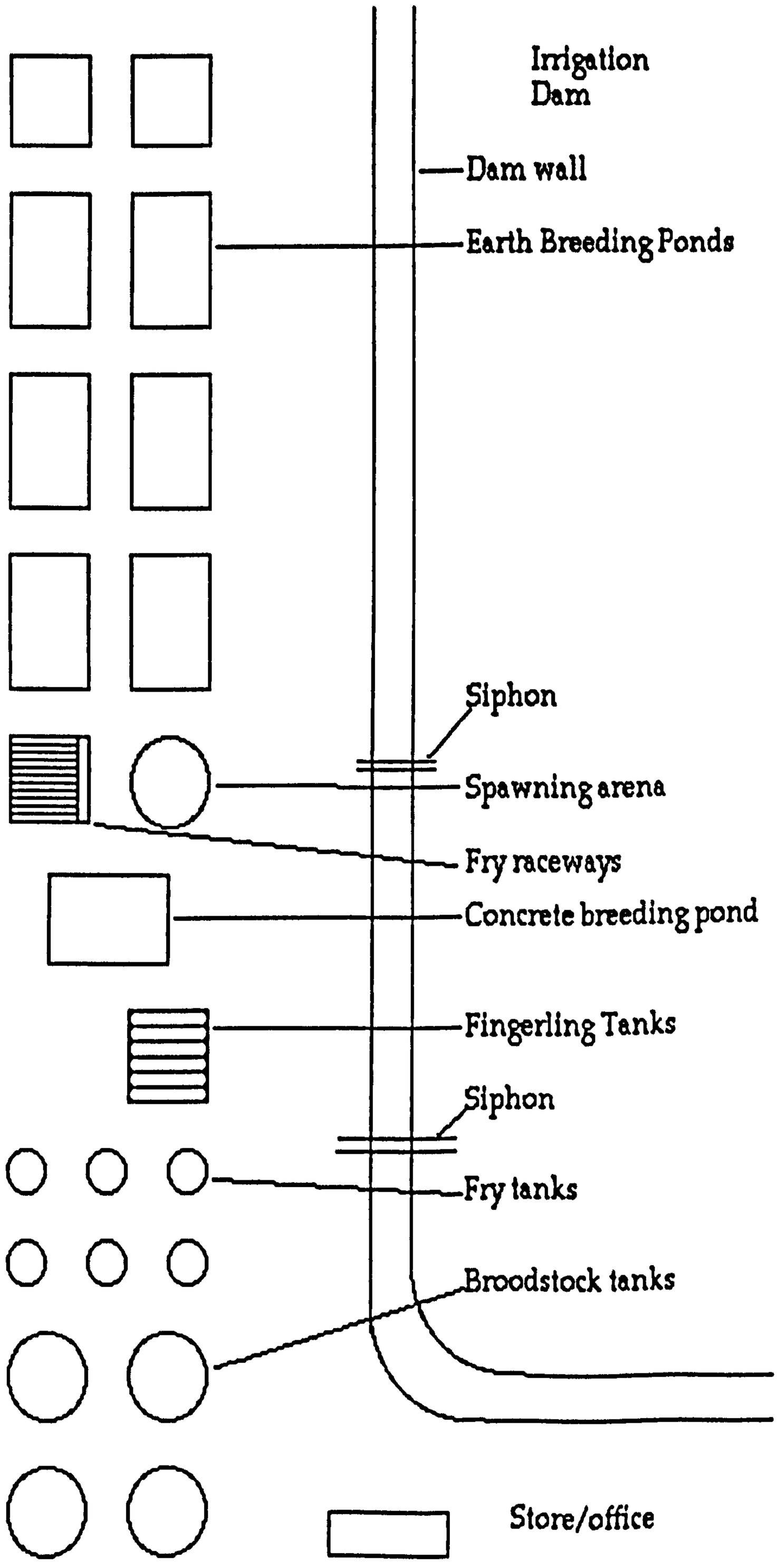
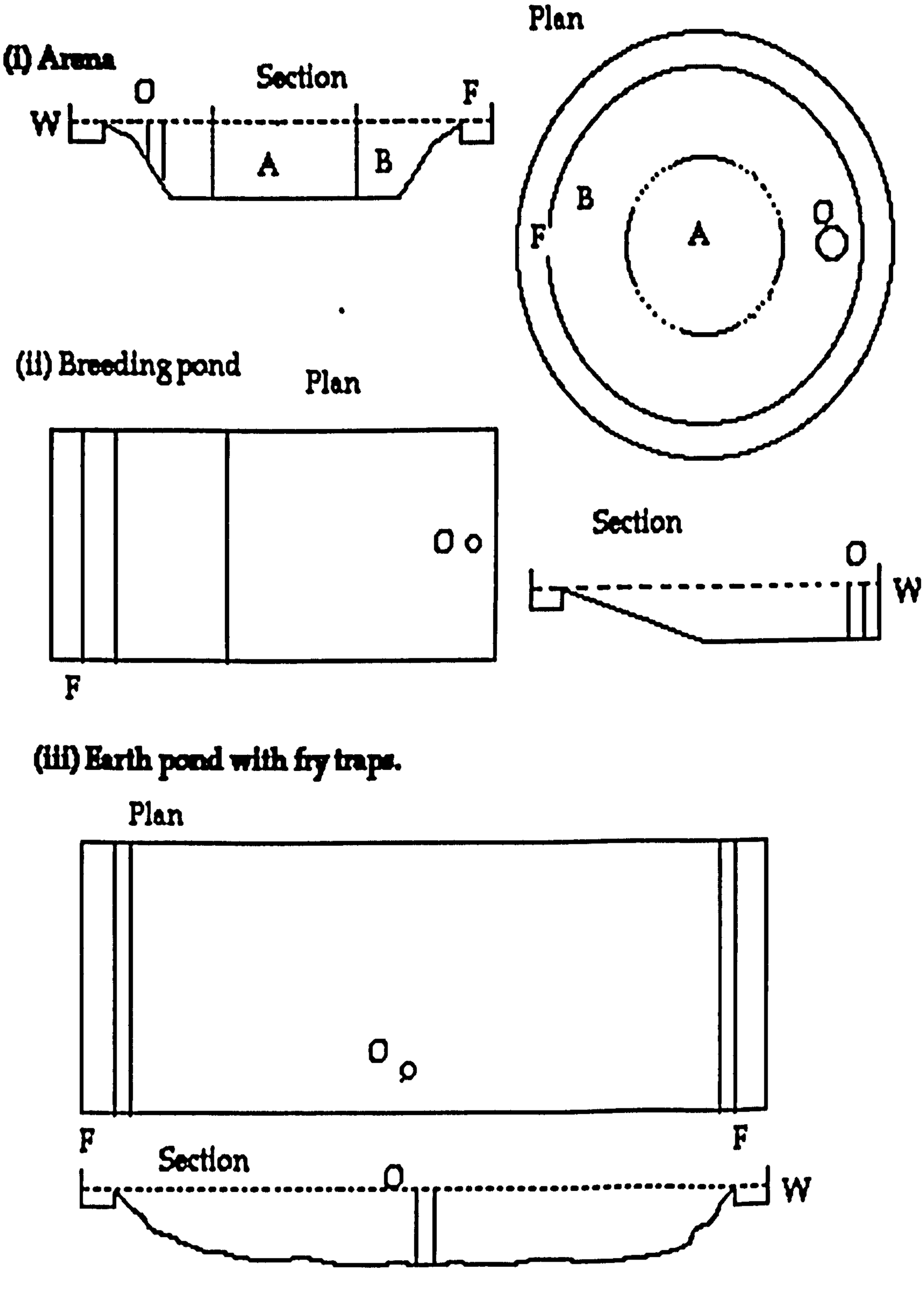


Table 3. The characteristics of tanks at the hatchery and rearing unit.

	No.	Dimensions	Stocking	Water Flow	Water Source
Hatchery					
Arena	1	15m dia. round 1 m. deep	40 males 280 female	$1m^3/hr$	Borehole
Breeding pond	1	10 x 20 m. 1 m. deep	40 males 280 female	$1m^3/hr$	Borehole
Earth ponds	6	30 x 12 m. 1m deep	40 males 280 female	$0.5 m^3/hr$	Dam
Broodstock tanks	4	8m dia.round 0.7m deep	Broodstock	$0.6m^3/hr$	Borehole
Fry raceways	11	10 x 0.7 m 0.2m deep	5000 fry	$0.6m^3/hr$	Mixed Dam/ Borehole
Fingerling tanks	6	5m dia.round 0.7m deep	10000 - 15000 1 - 5g fish	$1m^3/hr$	Dam
Fingerling raceways	6	9.5m D-ended 1m deep	10000 5-15g fish	$6m^3/hr$ +aeration	Dam
Rearing Unit					
Rearing Tanks	20	9.5m D-ended 1m deep	5000 fish @200g	$8m^3/hr$ +aeration	Factory Raw water
Test tanks	10	3m x 0.7m 1m deep	Variable	$1m^3/hr$	Borehole
Holding tanks	3	2 x 2m 0.5m deep	Variable	$1m^3/hr$	Borehole

Figure 4. Spawning pond designs used at Nakambala.
(not to scale - see Table 3 for precise dimensions)

O=water outlet; F=fry collection channel; W=water level.



(iv) Earthponds - same as (iii) except no fry collection channels.

(i) Spawning arena.

This was modelled on observations of a system which had been developed at Baobab Farm, Kenya (Haller, personal communication). It was constructed from concrete and plastered brick and was designed to exploit the mouth brooding behaviour of tilapias to ease management of the system (see section 3.2). The tank was divided into three zones. Zone A, in the middle, was the area reserved for male tilapias to nest in. This zone was separated from the rest of the tank by a wall with apertures which were fitted with wire mesh grids. The males which were stocked into the tank were selected so that they were too large to pass through the mesh grids (300g+). Females were selected to be of a size which could pass through the grids (<200g). They could pass freely between zone A and zone B. The intention was that males would construct nests in zone A. Females, when they were ready to lay eggs, would pass into zone A, lay eggs in the nest of a male and after fertilisation of the eggs by the male, would pick the eggs up by mouth and return to the relative quiet of zone B to incubate the eggs. Fry, on release by the female, would be attracted into the sloping area leading to the fry collection channel and into the fry collection channel. The channel was then emptied of fry when sufficient numbers had collected in it, by flushing them directly into the fry raceways.

(ii) Breeding pond.

This was built as a cheaper version of the arena. It was built with a concrete floor and plastered brick walls. It was rectangular in shape (10m x 20m) with one fry collection channel at one of the shorter ends. No dividing wall was constructed to separate males from females. Fry were collected in the fry collection channel using a fine mesh net, and transferred in the net into the fry raceways.

(iii) Earth pond with fry collection channels.

Two 30m x 12m earth ponds were excavated by hand. The bottom was left as earth, but the walls were lined with plastered brick. A fry collection channel was built at each end of both ponds.

(iv) Earth ponds.

Further ponds were excavated by hand but were not fitted with fry collection channels.

Fry from all of the breeding ponds were transferred to the fry raceways. These were shallow raceways fitted with fine mesh outlet screens (1mm). Because of the low rate of water flow (0.6 m^3/hr), these were not self cleaning. Feeding of the fry with artificial feed started in the raceways, meaning that they had to be cleaned out daily.

As soon as the fish were large enough they were transferred into the fingerling tanks. These were round tanks with centre screens. Inflow of water was controlled by valved two inch pipes with sparges which directed the flow tangentially in the tank. These tanks were self cleaning.

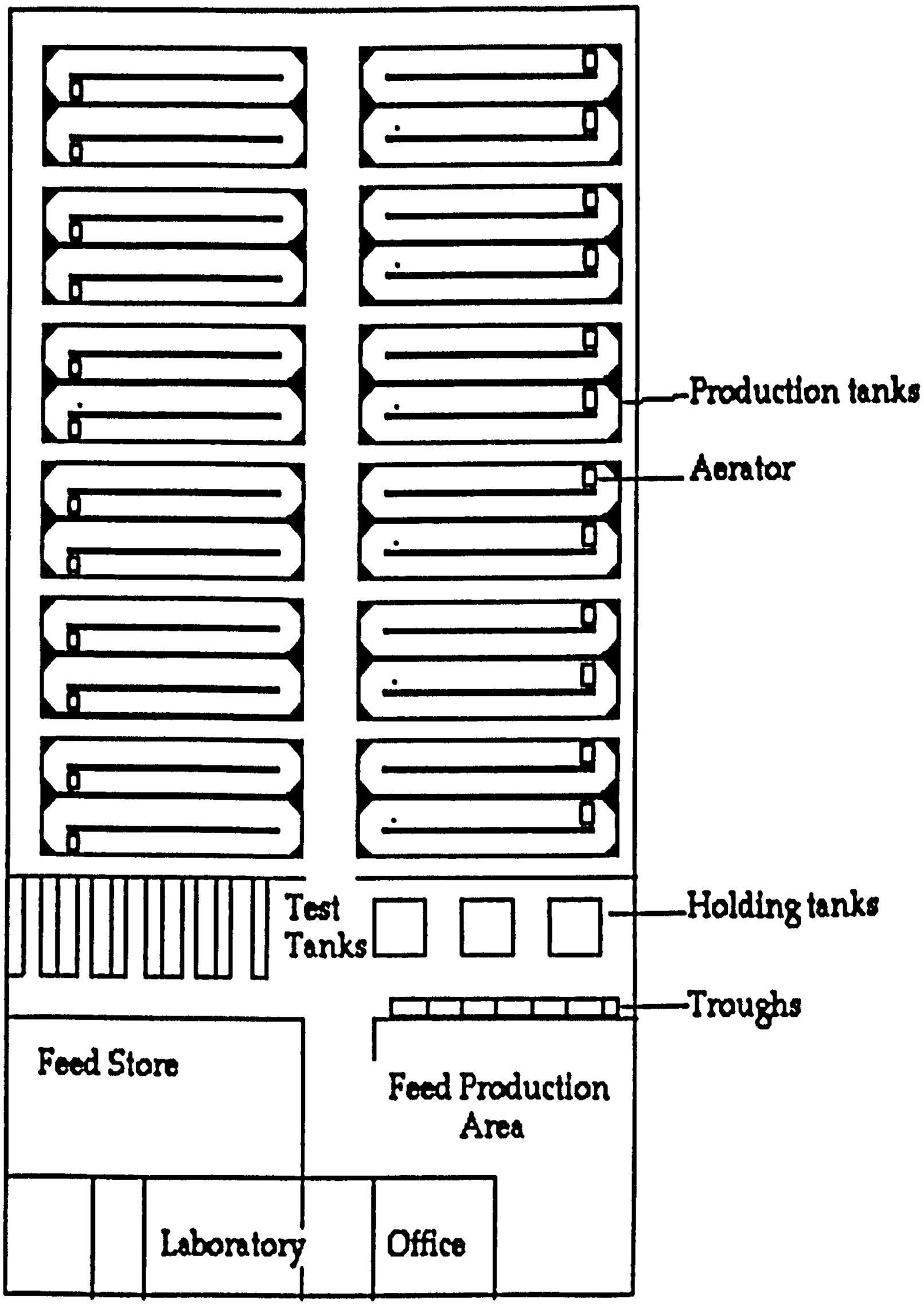
Following the fingerling tanks the fish were transferred to 6 D - ended tanks. All the pipework for these tanks was found locally. Construction was similar to the production tanks at the Rearing Unit (see below).

Figure 5 shows site B - the Rearing Unit.

Water was supplied to the Rearing Unit through a pipeline from the main water header tank in the sugar factory. This in turn was filled by gravity from a dam on the estatewhich was filled with water pumped from the Kafue River. The farm pipeline also had the facility to draw water directly from the dam, bypassing the sugar factory header tank. Water from the factory header tank passed by an eight inch steel pipe to a mixing tank situated halfway between the farm and the factory. This was constructed to allow mixing of ambient temperature water from the factory header tank with warm water from the factory cooling system to raise Winter water temperatures on the farm so that fish growth could be maintained throughout the Winter. The sugar factory normally only operated during the dry season (April - October) which coincided well with the farm requirement for warm water of May to September (see Figure 2). Factory cooling water was normally recirculated repeatedly round the factory cooling system. The cooling water was intercepted on the way to the cooling ponds at which point it the normal temperature was 40 - 45°C. Apart from the mornings of two days each week when maintainence work was being carried out in the sugar factory, the pressure in the supply pipe to the cooling ponds was sufficient to lift water to the mixing tank. During the maintainence periods, a pump was used (3 kw electric pump). Mixing was controlled manually by adjusting the settings on the valve supplying dam water and the valve supplying warm water at the mixing tank. Water temperatures were checked every hour and maintained at 25°C (+/-2) throughout the Winter.

The mixing tank also served as a direct header tank for the farm, evening out fluctuations in pressure from the main factory header tank and reducing the working head on the farm to a safe level. Water was carried from the mixing tank to the farm by a buried eight inch asbestos pipe. The normal flow rate of water through the pipe

Figure 5. Site layout at the rearing unit.



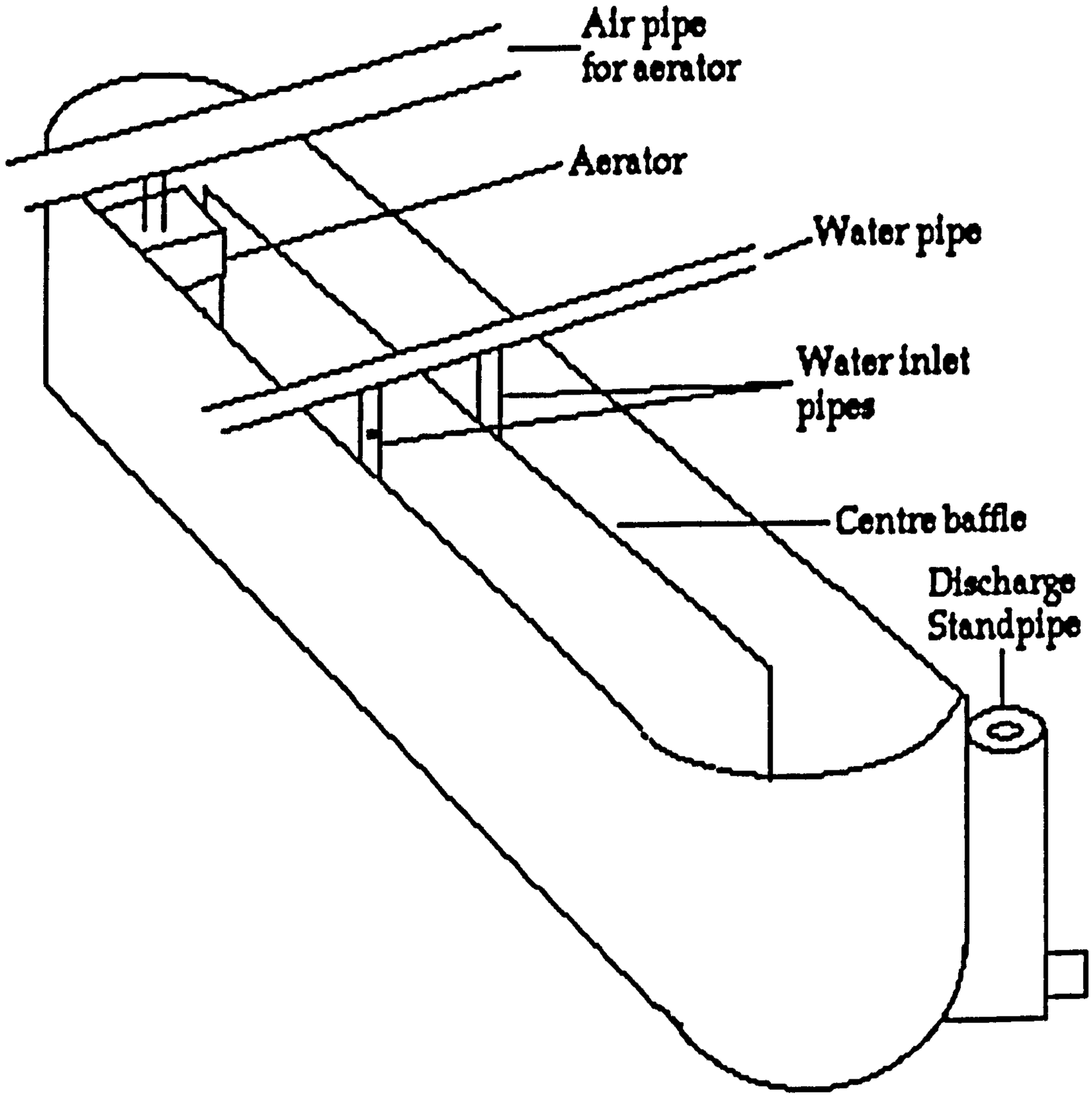
was 160 - 180 m^3/hr, however the pipeline could have carried much higher volumes than this.

A borehole was drilled at this site as a back-up water supply. The yield was approximately 3 m^3/hr and this was normally used to supply the non-production tanks.

Figure 6 shows a schematic diagram of one of the main production tanks. Tanks 11-20 were constructed from kits supplied by Kingfisher Tanks Ltd, Essex, England, consisting of polystyrene filled glass reinforced concrete panels, assembled on a prepared base, glued together and held together with straps. Tanks 1-10 were built out of locally available materials, with concrete bases and plastered brick walls of the same dimensions as the imported tanks. Despite constuction costs for the locally built tanks being similar to those for the imported tanks, local construction was obviously preferable because it did not involve the purchase of foreign exchange. All the tanks used imported fittings including inlet pipework, outlet pipework, outlet sumps and aerators. Water flow to each tank was through two, 2 inch, valved, inlet pipes with directional jets so that a directional water flow was set up in the tank. The normal flow rate of water into each tank was 8 m^3/hr.

Each tank was continuously aerated using directional flow aerators (Kingfisher Tanks Ltd). The aerators were designed to lift water from the bottom of the tank and eject it at the surface in the same direction as the water flow set up by the water inlet jets. This achieved thorough mixing of the water in the tank coupled with aeration. With the aerators in operation, the normal water flow around the tank was 5 m/minute, without aeration the flow dropped to less than 2 m/minute. The main function for flow was to keep solid wastes in suspension until they were removed with water passing through the outlet screen. The level of water in the tank was maintained by a

Figure 6. Production Tank Detail.



standpipe on the outside of the tank. Although most of the solid wastes were removed from the tank during normal operation, the tanks were flushed periodically (2 x /day) by removing the top section of the standpipe. This removed any accumulation of wastes which might build up around the outlet screen or sump.

Each set of ten tanks was supplied with air from a centrifugal blower originally supplied with 5 horse power electric motors. Within the first few months of operation, both motors had burnt out, probably as a result of overheating due to voltage fluctuations caused by lightning storms. The motors were rewound in the factory workshop, however they continued to burn out and the situation was not resolved until they were replaced with 7.5 horse power motors.

The feed processing system is described in Chapter 4.

CHAPTER3. OPERATION OF NAKAMBALA TILAPIA FARM.

3.1. Designed performance of the production system.

This chapter concentrates solely on results from the production system. Results of experiments carried out in research tanks are described in Chapter 7.

The farm was designed to operate as shown in Table 4, giving a total production cycle of eight months. This was, however, complicated by the fact that breeding was seasonal so the Hatchery had to hold fluctuating stocks of juveniles depending on the season, to allow continuous production at the Rearing Unit.

Table 4. Operation of the farm.

	Fish Weight		Period of
	Start	Finish	Time in Tank
Fry Raceways	Fry	1g	3 weeks
Fingerling Tanks	1g	5g	3 weeks
Fingerling Raceways	5g	15g	6 weeks
Production Tanks	15g	200g	5 months

TOTAL = 8 months

It was anticipated that the farm would produce 50 tonnes of fish per annum. It was also felt that this production should be based on hybrids of *Oreochromis niloticus* and *Orechromis aureus* as hybrids had been reported to have significant advantages over purebred tilapias in terms of growth (Avault and Shell, 1966; Pruginin et al, 1975; Hough, personal communication).

3.2. Fish breeding performance.

The breeding behaviour of the nest building, mouth brooding tilapias, to which all the species being considered for cultivation at Nakambala belonged, has been described by a number of authors (Maar *et al*, 1966; Huet, 1972; Balarin and Hatton, 1979). The male fish makes a nest on the bottom of the pond by scooping out a shallow depression with his body and lifting material from the centre of the nest to the outside with his mouth. The precise form of the nest varies with the species (Maar *et al*, 1966). The female, when she is ready to spawn, approaches the nest and is actively courted by the male. After some time, the female lays her eggs in the nest, which are fertilised immediately by the male. The female then picks the eggs up in her mouth and leaves the nest area, leaving the male free to pursue another female. The female incubates the eggs in her mouth for a period of around 5 days (depending on the species) and holds the fry in her mouth for up to two weeks. When the fry first appear from the mouth of the female, they retreat quickly on the first sign of danger. Gradually they become more independent so that at three to four weeks, they have left the female completely. In most species the female can lay another batch of eggs within two to three weeks of leaving the fry, provided the water temperatures remain sufficiently high. The fry, on leaving the protection of the female, are very vulnerable to predation. They generally congregate in shallow and warm water.

Because none of the local species of tilapias had been shown to be capable of being farmed intensively, *Oreochromis niloticus* and *Orechromis aureus* were imported in June 1982. Approximately 200 of each were bought from the University of Stirling at sizes of between 1 - 5g each. Substantial mortalities of these were encountered, reducing the surviving numbers of individuals at the end of the Winter in 1982 to around 200 *O. aureus* and 23 *O. niloticus* As it was clear that it would be some time before these fish could be used as the broodstock for the farm, it was decided to stock

the farm with some of the indigenous cichlids. The most abundant in the Upper Kafue system were *Tilapia rendalli*, *Oreochromis macrochir* and *Oreochromis andersonii*. *O. macrochir* in particular were readily available in irrigation dams on the sugar estate. Maar *et al* (1966) reported that *O. macrochir* was widely used in fish culture in Zambia and further north, however growth was lower with *O. macrochir* than with *O. andersonii* in pond culture. Following a number of unsuccessful fishing trips on the Kafue river, during which less than ten *O. andersonii* were caught, it was decided to stock the breeding system with *O. macrochir* from the irrigation dams. Each of the first two breeding ponds, (the arena and breeding pond 1) were stocked with 280 females (150 - 200g individual weight) and 40 males (300g +) of *O. macrochir* in September 1982. This sex ratio was based on advice from Baobab Farm in Kenya (Balarin, personal communication). Breeding commenced almost immediately. The fish were fed fingerling food (see table 11) at approximately 1% of body weight/day and fry removed periodically (see discussion below on spawning systems). These fish were used as the main broodstock throughout the 1982/3 breeding season. Subsequent growth of the progeny proved to be disappointing (see Table 6), so the breeding ponds were stocked with *O. andersonii* and *O. aureus* for most of the 1983/4 breeding season. In 1984/5 the breeding programme was widened to include *O. niloticus*/*O. aureus* hybrids and pure *O. niloticus* The fry production rate of the hybrids was very poor (see Table 5) so breeding concentrated from 1985 onwards on pure *O. niloticus*

Table 5. Record of tilapia fry production for each year (Fry/female/month).

Species	1982/83	1983/84	1984/85	1985/86
Oreochromis macrochir	76	-	-	-
Oreochromis andersonii	-	69	-	-
Oreochromis aureus	-	57	32	-
Oreochromis niloticus	-	-	28	63
O.niloticus x O.aureus	-	-	7	-

Table 5 summarises the breeding performance of the different species over complete breeding seasons. These figures were calculated by counting up the number of surviving fry of each species in the production tanks at the end of each breeding season. These totals were divided by the number of females of each species used for breeding in that season and the number of months during which those females were actively reproducing to give a figure of fry per female per month. Although these incorporate a number of variables including changes in husbandry techniques with time and the particular breeding system used for each species, they can be used as a rough comparative guide for the different species. Some species bred more easily than others. *O. macrochir* showed the highest fry production rate at 76 fry/female/month, whilst hybridisation between *O. niloticus* and *O. aureus* produced a very low fry production rate of 7 fry/female/month. This poor breeding performance ruled out the concept of farm production being based totally on hybrids.

Improvements in management of breeding ponds accounted for the rise in breeding performance of *O. niloticus* between 1984/5 and 1985/6. The principle change in management was the rigorous emptying of each breeding pond every month. Without this frequent emptying it was found that despite fry being collected regularly from fry collection channels, some fry would remain in the pond. These fry rapidly became cannibalistic on newly hatched fry thus reducing the overall fry production from the pond. This problem was also described by Berrios-Hernandez and Snow (1983). They found that with *O. aureus* spawning in small plastic ponds, the highest productivity was achieved by removing eggs from the females and hatching artificially (580 fry/female/month) whereas the most economical system was to remove fry from the pond after they had been released by the female (560 fry/female/month). Leaving the fry in with the broodstock resulted in fry production of 16 fry/female/month.

Although these figures are not directly comparable with those in Table 5 because the Nakambala figures are calculated from surviving fingerlings at the end of the breeding season and not swim-up fry, the productivities achieved in these experiments indicate that there is scope for improvement in broodstock management at Nakambala.

Maar *et al* (1966) suggest that *O. macrochir* females should be able to produce 3000 - 4000 eggs/annum (500 - 600 eggs/female/month), although it is clear that not all of the eggs will be viable. In an artificial hatching system in which the eggs were removed from female *Oreochromis mossambicus*, Subasinghe and Sommerville (1985) found that only 55 - 62% of the eggs survived to hatching if prophylactic disinfection was not carried out. Santiago *et al* (1985) demonstrated the importance of a high quality broodstock diet in terms of fry production and maintainence of broodstock condition. They achieved fry production rates with *O. niloticus*, in suspended cages (hapas) and small tanks ranging from 21 - 336 fry/female/month. The breeders were either fed no supplemental feed at all, a feed containing 20% protein, or one containing 40% protein. Highest fry production rates were consistently shown in those fed the 40% protein feed. Another factor which has a strong influence over fry production is the size of the female. Ruwet *et al* (1975) reported that the number of eggs produced by female *O. niloticus* ranged from 186 for a fish of 112mm total length to 545 for a fish of 140mm total length.

Four designs of spawning pond were used over the course of the project as described in section 2.3. Systematic data were not collected on the fry production rates of each system because fry were generally not counted until they were transferred as fingerlings from the hatchery to the rearing unit. By this time the individual batches had been mixed by amalgamation and grading of the fish so that the origins were unclear. Comparison of the productivity of the different types of breeding ponds is

based on visual estimation of the number and frequency of fry transfers from the breeding ponds to the raceways.

(I) The arena was expensive to build (ZK11000 in 1982). Although the fry collection system worked well, some of the fry remained in the centre sections and had to be removed periodically to stop cannaballism. The circular configuration and the separate compartments made it very difficult to catch the fish.

(ii) The breeding pond cost considerably less to build than the arena (ZK6000 in 1982). It proved to be no less productive and because of the rectangular shape, sloping bottom and lack of compartments, it was much easier to catch the fish when the tank was being emptied. Another advantage of the lack of compartments was that there was no restriction on the size of female which could be used. As discussed above, large females produce more eggs per batch.

(iii) Earth ponds with fry collection channels. These were built in 1983 at a cost of ZK2500 each. Fry collection from the channels combined with emptying every 4 - 6 weeks, allowed these ponds to achieve similar productivities to those in the arena and breeding pond. Care had to be taken when the ponds were emptied, as the nests made by males left puddles of water in which substantial quantities of fry could survive if they were not emptied out completely.

(iv) Earth ponds were excavated by hand at an approxdmate cost of ZK1000 each. If they were managed properly by emptying every 4 - 6 weeks, the fry production was just as high as with the other systems.

The conclusion of the comparison between the systems was that an easily emptied earth pond was probably as effective as more elaborate stuctures such as the arena and was considerably cheaper.

3.3. Growth of fish in the production system.

Fry from the breeding ponds were stocked into the fry raceways, where feeding with artificial feeds commenced. The fish started off being hand fed, on fry powder food, *ad libitum*. The raceways were stocked by eye, in the region of 3000 - 5000 fry/raceway. The fish remained in the raceways for 3 - 4 weeks. Movement of the fish was not carried out until they looked strong enough to withstand the higher current velocities in the fingerling tanks. Average weight at this stage was less than one gramme.

Generally three raceways were stocked into each fingerling tank. Feeding in the fingerling tanks started with fry powder but was changed soon afterwards to a mixture of fry powder and fingerling crumble fed *ad libitum* The fish remained in the fingerling tanks for 3 - 4 weeks before being transferred to the D - ended tanks. By this time they were being fed wholly on fingerling crumble. The quantity of food fed was determined by sample weighing of the fish (see below) and calculating a daily ration for each tank. Although this ration was based on a %age of the body weight of the fish, this was not fixed and was adjusted according to observations on growth and performance of the fish. They remained in the D - ended tanks for at least 6 weeks, growing from around 3g to between 5 - 10g. At this size they were graded (by hand on a grading table), and transported in plastic drums half filled with water to the rearing unit. This growth cycle in the hatchery meant that the first fingerlings of the breeding season (hatched in October) were available for transfer to the rearing unit in January/February.

Each of the rearing tanks was stocked with around 10000 fingerlings of 4 - 10g average weight. These were fed a daily ration by a combination of hand feeding and with demand feeders, initially continuing on fingerling crumble, but transferring to pelleted grower food at 30g average weight. Grading and separation of the fish was

carried out at between 50 and 100g to leave 5000- 6000 fish/tank. The target weight was 200g/fish although fish of under this size frequently had to be sold to maintain turnover.

Fish in all the tanks at the rearing unit and fish in the fingerling and D - ended tanks at the hatchery, were routinely sample weighed every two weeks. The water level in each tank was lowered and a sample of at least 100 fish was collected by hand net. The fish were then anaesthetised in benzocaine (1:15000) and bulk weighed using a bucket and hanging scales. From these weighings rations were calculated and records kept on growth rates and food conversion ratios.

Table 6 summarises the growth rates achieved in the Rearing Unit over the period 1982 - 1986. The figures are calculated from tanks of fish on which at least four consecutive weighings had been carried out without fish being added or taken out (except for routine mortalities). Whilst they are split up into different species they also relate to other variables such as different stocking densities (10 - 100kg/m3), size ranges(5 - 200g) and feeds (see chapter 5). Generally it can be seen that growth rates improved with time, reflecting that the species of fish stocked were capable of faster growth and that husbandry conditions improved to allow expression of that growth potential.

Immediately after the farm was commissioned the rearing unit was stocked with juvenile *Tilapia rendalli* netted from irrigation dams. These showed very poor growth and were replaced in early 1983 with *O. macrochir* produced in the Hatchery. Although initial growth looked promising, this was not sustained and growth slowed dramatically once the average weight of the fish reached 70 - 80g (S.G.R.'s < 0.1). This was at stocking densities of less than 30 kg/m^3, which was much lower than the stocking densities used by T.L.T.S. at Tihange in Belgium (Hough, personal

Table 6. Average Specific Growth Rates* in the Rearing Unit 1982 - 1986.

	S.G.R. of fish resulting from fry produced in season			
	1982/83	1983/84	1984/85	1985/86
O. macrochir	0.45+/-0.41(12)	-	-	-
O. andersonii	0.91(1)	1.46+/-0.13(4)	1.75(1)	-
O. aureus	1.06(1)	1.76+/-0.55(7)	1.64+/-0.47(18)	-
O. niloticus	-	-	2.03+/-0.41(5)	3.28+/-0.48(8)
O.niloticus x O. aureus	-	1.75+/-1.15(2)	1.78+/-0.59(4)	-
Cyprinus carpio	-	-	2.98+/-0.32(2)	3.1(1)

Figures presented as: Average S. G. R.+/-Standard deviation(No. of samples).

* Specific Growth Rate(SGR) = $(\log_e w_2 - \log_e w_1).100/t$

w_1 = average weight of fish at start of test period; w_2 = average weight of fish at end of test period; t = length of test period in days.

communication). Nevertheless one of the tanks was split into two tanks, with no consequent improvement in growth rates. This led to the conclusion that *O. macrochir* was inherently unsuited to intensive culture. The few *O. andersonii* and *O. aureus* hatched in 1982/3 grew much better than the *O. macrochir.* (see Table 6).When fry of these species became available the following year they were stocked into the farm along with one tank of *O. aureus/O. niloticus* hybrids. *O. aureus* achieved higher growth rates than *O. andersonii* and similar growth to that of the hybrids. The following year more *O. aureus*, *O. niloticus*, *O. aureus/O. niloticus* hybrids and Mirror Carp became available for ongrowing. As can be seen in Table 6 highest growth was achieved in *O. niloticus* and Carp. Fry production in the 1985/86 breeding season had concentrated on *O. niloticus* and at the time of completion of the study (December 1986) these fish were showing the most consistently high growth rates achieved at any time on the farm.

These growth rates compare well with those quoted by other researchers. Maar *et al* (1966) quoted growth rates corresponding to S.G.R.'s of 1.42 and 0.92 for *O. andersonii* and *O. macrochir* respectively, in ponds. Viola and Zohar(1984) reported specific growth rates of between 0.67 and 1.44 with large(106g+) hybrid tilapias (*O.niloticus x O.aureus*) in a variety of trials. Zohar, Rappaport and Sarig (1985) reported specific growth rates of up to 1.31 with 140g male *O.niloticus x O.aureus* in intensive tanks. Higher growth rates are normally observed in small tilapias than in larger fish. Barash (1984) reported specific growth rates of 3.2 to 4.8 for *O. niloticus x O. aureus* hybrids and "Red Tilapia" from Taiwan of weights between 0.8g and 33g.

3.4. Food conversion ratios in the production system.

Food conversion ratios(weight of food fed divided by total weight gain of fish) were calculated for each tank on a fortnightly basis. This was used to calculate the ration for the fish in each tank for the following two weeks. The data collected has not been analysed systematically because it was felt that there were too many inconsistencies over the course of the project. F.C.R.'s depend not only on the performance of the fish, but also on the feeding rates employed by the farm manager. In situations where there is low growth, F.C.R.'s quickly become large numbers, and where there is no growth or weight loss, the F.C.R. becomes infinite. It was found that these anomalous results tended to skew F.C.R. figures. It was decided instead to work out Food Conversion Ratios for the farm. This was calculated at three points near the end of the study by dividing the weight of food used on the farm in each month, by the weight of fish production (estimated fish weight gain + weight of fish sold) during that month. The results are shown in Table 7. As can be seen, food conversion ratios improved dramatically between September 1985 and March 1986. This was probably as a result of improved feed formulations and improved strains of fish held on the farm. Food

conversion ratios reported from Israeli researchers vary from 1.15 to 4.2 (Barash, 1984; Zohar, Rappaport and Sarig, 1985; Viola and Arieli, 1983), but figures around 2 are usually considered to be reasonable (Jauncey, personal communication).

Table 7. Food Conversion Ratios for the Farm from September 1985 to March 1986.

	Weight of food used (tonnes)	Weight gain of fish (tonnes)	Food Conversion Ratio
September 1985	9.2	2.8	3.28
January 1986	8.92	3.68	2.43
March 1986	7.25	3.53	2.05

3.5. Choice of fish species for culture.

The two most important factors which emerged during the study regarding choice of species to be farmed, were ease of breeding and achievable growth rates. Of the indigenous species, *O. andersonii* showed the highest potential with high fecundity and reasonably high growth rates. This is consistent with Maar *et al* (1966), who suggested that *O. andersonii* shows better growth than *O.macrochir* in ponds, however they also suggested that only one brood of eggs per season was produced by each female *O. andersonii* and that the number of eggs produced was lower than for other species. This is not consistent with the data presented in Table 5 which shows that *O. andersonii* was the second most prolific breeder. *O. niloticus* became the first choice once a broodstock population had been built up as fry production rates were high and growth rates were well above any of the other cichlids. Concentrating on *O. niloticus* also removed the considerable problems brought about by trying to maintain several distinct broodstock lines. This meant that all the available tanks and ponds were able to be utilised for fish production.

CHAPTER4. FEED RAW MATERIALS AND THEIR AVAILABILITY IN ZAMBIA.

4.1. The Zambian Animal Feed Industry.

The Zambian animal feed industry is relatively young, developing in the late 1960's and through the 1970's. It was built up to service the needs of the intensive poultry, pig and cattle rearing enterprises which arose at this time, to provide good quality meat to the increasingly urbanised population. The feed industry was based on conventional formulations used in more developed countries, which necessitated the importation of many of the ingredients such as fish meal and vitamin premixes.

In the late 1970's and early 1980's the Zambian economy declined rapidly, mainly due to a weakened market for the principle export, copper. This resulted in foreign exchange becoming very scarce. At the same time the Zambian currency was protected by exchange control restrictions so that it was overvalued compared to other currencies. Although foreign exchange was scarce, this made imports cheap so there was no incentive to replace imported ingredients with relatively expensive locally produced ingredients.

The situation became worse in 1984 and 1985 so that foreign exchange became almost impossible to obtain. As the feed industry was still using formulations requiring high levels of imported ingredients, this led to the virtual collapse of the poultry and pig farming industries. In late 1985 a new system was introduced for the allocation of foreign exchange which resulted in the Kwacha being drastically devalued. This new system made access to foreign exchange easier, but also much more expensive, which put pressure on the feed manufacturers to use more locally grown materials. This also

led to Zambian crop farmers receiving better prices for their produce which stimulated them to produce more. In this new situation the feed companies tended to import only what was actually essential such as concentrates of vitamins, minerals and essential amino acids.

This was the economic climate that the Nakambala Tilapia Farm had to operate in. Following from the decision to farm using an intensive system, it was essential to provide a complete feed for the fish. This feed would have to be produced totally from locally available ingredients otherwise the project would have no hope of being sustained, given the uncertainties surrounding the availability of foreign exchange.

4.2. Feed Analysis.

The Nakambala Tilapia Farm did not have facilities for the nutritional analysis of feedstuffs. This meant dependance on outside analysts to test feeds used in feed trials and routine testing of production feeds. A variety of analysts were used:

(1) Tate and Lyle Research and Development(T.& L.), Reading, England.
(2) Institute of Aquaculture, University of Stirling, Stirling, Scotland.
(3) National Milling Company, Lusaka. (N.M.C.)
(4) National Council for Scientific Research (N.C.S.R.), Lusaka.
(5) National Irrigation Research Station (N.I.R.S.), Nanga, nr. Mazabuka.

Both Tate & Lyle and Stirling carried out proximate analysis (crude protein, ether extract, crude fibre and ash) as well as amino acid analysis, however it was often difficult to get samples to them as they could not be posted in Zambia and so had to wait until they could be hand carried for posting in U.K. Whilst the results were undoubtedly accurate they were usually slow in coming, often taking a number of months.

The National Milling Company and the National Council for Scientific Research were equipped to carry out proximate analysis, but could only test a limited number of samples and were slow to return with results.

The National Irrigation Research Station was only 10km from the sugar estate. It was quite well equipped for soil analysis and had a British trained chemist. It was always short of chemicals but an arrangement was made where chemicals were supplied by Nakambala for the testing of samples from the fish farm. N.I.R.S. was only equipped to test for moisture, crude protein and ash, however results were usually ready within two days, making the facility ideal for routine sampling of feeds.

The methods used in all the laboratories were based on A.O.A.C. methods(Horwitz, 1980). Amino acid analysis at the University of Stirling was with an LKB 4151 alpha plus amino acid analyser, following manufacturers recommended procedures for protein hydrolysates.

Because of the limited analytical facilities available, most analyses are the results from a single sample of feed or feed ingredient, however care was taken to ensure that the sample was representative of the complete batch by amalgamating at least two subsamples from different parts of the same batch or container.

4.3. Fish and Fish Products.

In Zambia, fish form a substantial part of the human diet, providing about two thirds of the animal protein consumed in the country (Black, 1981). A wide range of species are caught in the rivers and lakes and almost any size or type is acceptable for human consumption. The original plan for the fish farm was to process fish caught in the irrigation dams into fish meal to use in the feeds. A list of species present in the dams is given in Table 8.

Table 8. Fish species caught in the irrigation dams on Nakambala Estate.

Oreochromis macrochir

Oreochromis andersonii

Haplochromis darlingi

Serranochromis angusticeps

Serranochromis macrocephalus

Serranochromis robustus

Tilapia rendalli

Tilapia sparmanii

Mastacembalus mellandi

Synodontis leopardinus

Clarias gariepinus

Schilbe mystus

Barbus spp.

Micralestes actidens

In most countries fish, in the form of fish meal, makes up the majority of protein in aquaculture diets (Hepher, Sandbank and Shelef, 1978). An alternative method of processing for small quantities of fish is the production of fish silage. This method is used in some specialised locations, particularly if the supply of fish for processing is not adequate for a fish meal plant to be constructed (Raa and Gildberg, 1982). Fish silage production is carried out by the addition or production of acid in minced fish or fish offal, so that the pH is lowered to levels where the silage is protected from degradation due to insects, fungi or bacteria. The advantages of fish silage production over fish meal production are (Raa and Gildberg, 1982; Gohl, 1981):

(i) The energy requirements are much lower.

(ii) It does not smell so much.

(iii) Capital investment in equipment is very low.

(iv) Fish silage is effectively sterile.

(v) Silage can be sun dried as the evaporating acids repel insects.

At the start of the project fish were caught in the dams and used in the feeds. Apart from a small quantity which were sun dried, they were usually made into a carbohydrate fish silage with molasses as described in Chapter 5. The results of proximate analysis of feedstuffs are presented in Table 9. This shows that the samples of fish silage which were taken, were very high in fat, probably because they were made up largely from fish offal left after gutting of large fish caught in the irrigation dams. The samples also had quite high ash levels. This resulted in a low average crude protein level of 30.3% of moisture free weight. There have been mixed reports on the

value of fish silage in feedstuffs. Wood, Capper and Nicolaides (1985) found that acid preserved fish silage contained similar amounts of crude protein but significantly lower amino acid and higher non-protein nitrogen levels than acid preserved cooked fish or fish meal made with the same material. In feeding trials, growth in carp was depressed by the replacement of fish meal or acid preserved cooked fish with fish silage. They suggested that this may have been due to leaching of ingredients or the action of thiaminase on thiamine levels in the feed. Raa and Gildberg (1982) reported that fermented fish silage had good nutritional quality with the biological value of the protein similar to that of skimmed milk powder or fish meal.

As the volume of fish feeds being manufactured increased, it soon became apparent that more fish would be required than could be caught in the dams. Although 56 hectares of dams were available, the productivity was very low. The highest average annual yield was in 1983 when 48kg/ha was caught. It was also clear that it did not make economic sense to turn fish which could be sold directly for human consumption into a fish feed ingredient. According to Barlow (1976) 1000kg of fresh fish will produce 212kg of fish meal. If this was used in a feed at a modest inclusion rate of 10%, then 47 tonnes of raw fish would be required to manufacture 100 tonnes of fish feed. At a food conversion ratio of 2:1 this feed would produce 50 tonnes of farmed fish, almost the same quantity of fish as was used to produce the fish meal. This is acceptable if the fish used in the fish meal cannot be used directly by humans or is of very low value but this was not the case in Zambia. High quality fish such as that produced on the fish farm commanded a premium over the small mixed fish caught in the dams but this was not enough to make it worthwhile to process the dam caught fish into fish feed.

Table 9. Nutritional analysis of feeds and feed ingredients (Crude Protein, Ether extract, Crude Fibre and Ash expressed as %age of Moisture Free Weight).

	Moisture	Crude Protein	Ether Extract	Crude Fibre	Ash
Fish Silage	72.4(1)	30.3(2)	43.4(2)	1.95(2)	16.4(2)
Dried Fish	72.8(1)	53.1(2)	25.1(1)	3.6(1)	16.8(1)
Kapenta	8.6(2)	69.9(3)	9.2(1)	N.D.	13.5(2)
Blood Meal(CSBZ)	9.0(2)	92.6(2)	0.2(1)	N.D.	5.0(2)
Carcase Meal(CSBZ)	5.8(2)	49.9(2)	11.5(1)	N.D.	24.3(2)
H.Feather Meal(Nak)	N.D.	71.9(1)	2.5(1)	18.1(1)	2.0(1)
Raw Soyabeans	6.7(1)	44.3(1)	11.8(1)	N.D.	4.7(1)
Soya Oilcake(Screw P)	N.D.	50.8(1)	3.4(1)	17.0(1)	6.2(1)
Full Fat Soya(Cooked)	9.5(3)	41.4(3)	15.7(1)	N.D.	4.8(2)
Sunflower Oilcake	6.3(6)	30.6(6)	2.1(1)	N.D.	5.8(4)
Cottonseed Oilcake	N.D.	19.5(1)	23.6(1)	23.9(1)	22.5(1)
Maize	10.4(1)	10.6(2)	3.7(2)	2.2(1)	1.6(2)
Wheatings	11.2(3)	14.7(4)	3.7(2)	4.0(1)	4.3(3)
Sorghum	10.9(1)	11.6(1)	3.5(1)	N.D.	1.7(1)
Bagasse / Molasses	13.3(4)	2.9(4)	0.5(2)	14.0(1)	9.4(1)
Leucaena	9.5(6)	22.8(6)	3.2(3)	8.5(1)	9.4(5)
Lucerne-Average	9.5(4)	27.9(8)	1.3(3)	N.D.	7.5(8)
- one week old	9.9(1)	34.4(1)	1.7(1)	N.D.	12.6(1)
- two week old	10.3(1)	26.2(1)	1.1(1)	N.D.	11.3(1)
- three week old	8.3(1)	20.3(1)	1.1(1)	N.D.	9.8(1)
Yeast	13.7(2)	44.2(2)	N.D.	N.D.	9.5(2)
Algae	N.D.	24.4(5)	0.8(3)	33.4(3)	32.5(4)

Each figure is the average of the number of samples indicated in parentheses. Raw material sources are described in the text of Chapter 4 and processing methods in Chapter 5. N.D. - not determined.

Table 9 (Continued). Nutritional analysis of feed ingredients (Essential Amino Acids as %ages of Crude Protein) (Analyses carried out by Inst. of Aquaculture, Univ. of Stirling).

	ARG	HIST	ISOL	LEU	LYS	METH	PHE	THR	TYR	VAL
Kapenta	3.3	1.7	2.9	4.6	5.4	1.4	2.8	2.9	2.1	3.4
Blood Meal	3.0	4.3	9.9*		7.1	1.4	5.5	3.8	2.3	6.4
Carcase Meal	6.9	1.4	7.2*		5.1	1.5	2.8	3.2	2.1	4.4
FullFat Soya	8.1	2.5	4.2	6.9	5.9	0.2	4.5	6.0	2.9	3.8
Sunfl'r oilcake	5.2	1.8	3.0	4.9	2.9	0.5	3.3	2.6	1.5	4.4
Maize	2.4	1.5	5.8*		1.7	0.9	2.0	1.7	1.2	2.8
Wheatings	3.7	1.3	1.4	3.2	2.2	0.2	2.1	1.8	1.3	2.3
Sorghum	4.5	2.9	23.2*		3.3	2.0	7.9	3.7	6.2	6.2
Leucaena	2.3	0.7	1.1	3.8	2.8	0.6	2.1	1.8	1.8	2.3
Lucerne	2.5	1.2	2.7	4.3	3.4	0.4	2.8	2.6	1.6	4.1
Tilapia reqs.	2.8	1.0	2.0	3.4	3.8	1.0	2.5	2.9	0.4	2.2

ARG = Arginine, HIST = Histidine, ISOL = Isoleucine, LEU = Leucine, LYS = Lysine, METH = Methionine, PHE = Phenylalanine, THR = Threonine, TYR = Tyrosine, VAL = Valine. Tilapia reqs. = requirements for tilapias as in table 2.

* In these cases the amino acid analyser was unable to distinguish between peaks for isoleucine and leucine.

Note: Tryptophan cannot be determined in acid protein hydrolysate.

During 1984 and 1985 dried fish were bought from Kafue Fisheries Ltd. near Kafue town. These fish came from an extensive tilapia farm which often had a large quantity of small tilapias at harvest, produced by over-reproduction of the adult fish. The farm found that it was easier to dry the small fish in the sun and sell them to Nakambala rather than sell them directly for human consumption . Whilst the analysis shown in Table 9 seems to indicate that the quality of the dried fish was reasonable, it was actually very variable. Insect infestation often left little apart from skin and bones, particularly during the rainy season, when sun drying would be slow and the fish may occasionally be caught in showers. Barlow (1976) referred to the problems relating to the sun drying of fish, including the likelihood of insect infestation and bacterial contamination, however he also acknowledged that it was still carried out in some parts of the world because there was little or no capital requirement for process plant and no running costs apart from labour. Purchase of this product at Nakambala was discontinued when other protein sources became available in reasonable quantities.

Most fishing in Zambia is carried out at an artisanal level in small boats using seine or gill nets. The only industrial scale fishing is carried out on Lakes Kariba and Tanganyika for kapenta. This is a small freshwater anchovy (*Limnothrissa miodon*), which is native to Lake Tanganyika and was introduced into Lake Kariba shortly after its formation in the late 1950's. Kapenta is usually caught by attracting a large shoal to a submerged light at night and drawing a net up from underneath the shoal. The fish are then sun dried and sold for human consumption. Because the product was sun dried the quality was not always uniform, particularly at the start and end of the rainy season when drying might be interrupted by rain. Interrupted drying often caused the kapenta to break up, which was not usually acceptable for human consumption. The fish farm was able to buy this as second grade kapenta at reasonable prices, although the supply was variable. Fairly regular supplies became available from 1985 onwards

and kapenta became one of the main protein sources in the fish feeds.Table 9 shows that kapenta contained high levels of protein, with a good distribution of essential amino acids. Although the amino acid levels are well below those published for ingredients such as Herring whole meal (Gohl, 1981), they compare favourably with the amino acid requirements suggested for tilapias (see table 2). In all cases the level of amino acids present in kapenta was higher than or equal to the the requirement.

Table 10 shows the availability and price of the different feed ingredients during the period of study. Kapenta became the main source of fish protein as the project progressed,becauseit was usually available, was easily handled and was of consistent quality.

4.4. Animal Byproducts.

These were used to make up for deficiencies in protein resulting from the shortage of fish proteins for the feeds.

The first animal protein source to be exploited was blood from Mazabuka Council Abbatoir. Blood was the only part of the slaughtered animals which was regularly available and was not used for human consumption. It was supplied free, the only cost being that of transport for collection. Raw blood is a very inconvenient material. It must be processed immediately or it quickly succumbs to bacterial spoilage. The usual process used at Nakambala was to mix it with wheatings or maize and sun dry it. The main disadvantage of this operation was the uncertainty of knowing the dry matter content of the dried blood. The blood collection system was poor and blood was often diluted with water. Two samples of blood mixed with wheatings at the same ratio on different days in July 1985 resulted in crude protein contents of 11.9% and 18.4%.

Table 10. Availability and prices of feed ingredients.

	Prices in Zambian Kwatcha/tonne in year			
Ingredient	1983	1984	1985	1986
Fish silage	800*	N.U.	N.U.	N.U.
Dried Fish	N.U.	3000**	3000**	N.U.
Kapenta	N.U.	1750*	2500*	3500*
Blood Meal	N.U.	N.U.	2000*	3800*
Carcase Meal	N.U.	N.U.	1750*	3500*
Soya Beans	511	322	676	1246
Sunflower Oilcake	N.U.	327	360	360
Maize	188	300	300	500
Cottonseed	N.U.	130	130	N.U.
Wheatings	N.U.	144*	160**	160
Molasses	N.U.	25	25	25
Leucaena	N.U.	N.U.	500	500
Lucerne	N.U.	N.U.	N.U.	500
Yeast	N.U.	700**	700**	1000**
Approximate exchange rate of ZK to £	2	5	8	13

N.U. = Not Used

* - Limited availability

**- Very limited availability (i.e. great efforts had to be made to secure supplies of the product)

There was no way of monitoring this variability on a day to day basis. Encouragement was given to the abbatoir supervisor to produce blood meal by boiling and coagulating the raw blood (as described in Gohl [1981]) in an open half oildrum but a dispute arose over the availability of firewood for fuel so production was discontinued.

During 1985 and 1986 significant quantities of commercially produced blood meal and carcase meal became available from the Lusaka plant of the Cold Storage Board of Zambia. These were produced from cattle slaughtered at the plant and were processed by dry rendering in a partial vacuum at 70°C. This source of blood meal proved to be very useful as the meal was of a consistent quality and was usually available. The quality of the carcase meal was varied, often containing visible lumps of bone. Table 9 shows that the crude protein content of blood meal was very high (average = 92.6%) and it was a valuable source of essential amino acids, particularly lysine. Carcase meal had a much lower crude protein content, partly because of high ash content, but was still a useful source of essential amino acids.

Another source of animal protein which was exploited was Hydrolysed Feather Meal produced from chicken feathers. These were processed according to methods described in Gohl (1981) (see chapter 5). In 1983 collection of chicken feathers from the Poultry Development Company in Lusaka started on a regular basis. The feathers were supplied free of charge, however they had to be collected from Lusaka and processed at Mazabuka using a pressure cooker made from an old compressor vessel heated over an open fire. Difficulties over transport led to feather collection being discontinued in April 1984. In late 1985 a pressure cooker was constructed at Nakambala Factory Workshop (see chapter 5). This was installed in the Lusaka plant of Zambia Pork and Poultry Products (Z.A.P.P.) who had taken over the Poultry Development Company.

The intention was that Z.A.P.P. would process the feathers and supply Z.S.C. with the resultant meal at an agreed price. Commissioning of the cooker took nearly a year and at the time of completion of the study, no significant quantities of hydrolysed feather meal had been supplied by by Z.A.P.P. to Z.S.C. Analysis of the resultant hydrolysed feather meals showed that they were high in protein(Table 9). Although Gohl (1981) reports that the amino acid balance is poor, the levels given are all equal to, or in excess of, the postulated requirements for tilapias.

4.5. Oilseeds.

Oilseeds are generally grown for their high oil content but the byproduct cakes from the oil extraction process, and in some cases the whole seeds, are valuable protein sources in animal feedstuffs (Gohl, 1981). Oil can be extracted from oilseeds by a number of methods:

(i) Hydraulic press. The seed is ground, heated and wrapped in a cloth before being subjected to intense pressure in a press. This causes the oil to be pressed from the seed.

(ii) Screw pressing. This is a continuous process which involves forcing the oilseed through a perforated barrel casing under pressure. The pressure and heat generated by friction rupture the cell in the seeds, releasing oil. This process was used at Nakambala and will be described more fully in chapter 5.

(iii) Solvent extraction. In this process, the ground seeds are placed in extraction vessels and covered with a liquid solvent (often hexane). Oil in the seeds dissolves in the solvent, the solvent is then removed and the process repeated until little oil is left in the meal. The solvent is distilled off the oil for reuse, and the meal is treated with steam to remove any residual solvent before drying.

Generally the efficiency of oil extraction is greater by solvent extraction (<2% residual oil), than by screw pressing (5 - 10% residual oil), and screw pressing than by hydraulic pressing (Gohl, 1981).

As well as oil extraction, oilseed processing is often necessary to reduce the effects of antinutritional factors. The toxic factors in soya beans have been listed as trypsin inhibitor, saponins, haemaglutin, lipoxidase, antivitamins, phytic acid, estrogens, flatulence factor and goitrogens, whilst cottonseed is reported to contain gossypol and cyclopropenoid fatty acids (Jauncey and Ross, 1982; Tacon *et al*, 1983). Many of the antinutritional factors in soya beans are heat labile and cooking is suggested as the easiest form of processing for soya beans (Jauncey and Ross, 1982; Gohl, 1981). Gohl (1981) suggests screw pressing as the best way to deactivate gossypol in cottonseed. Although the effects of these factors on tilapias have not been fully investigated, results of experiments carried out with other species show severe growth depression if untreated soyabean meals are used (Abel *et al*, 1984; Viola, Mokady and Arieli, 1983). Robinson *et al* (1984) suggested that *O. aureus* seemed to be relatively resistant to high levels of gossypol, the major anti-nutritional factor in cottonseed.

Soya beans, cottonseed and sunflower were used in feeds at Nakambala. Soya beans were either screw pressed or pressure cooked (see chapter 5). Cottonseed was screw pressed (see chapter 5). Sunflower oilcake was purchased from two sources. Refined Oil Products Ltd (R.O.P.) of Lusaka produced solvent extracted sunflower oilcake. The extraction plant was vastly oversized for the quantity of oilseed available, therefore the production of sunflower oilcake was intermittent, limited in 1985 to a single production run of 2 - 3 weeks. Chemical Products Ltd. of Lusaka produced screw pressed sunflower oilcake. This proved to be a more reliable supply as their extraction plant was much smaller and production was more or less continuous.

Nutritional analysis of the oilseeds and oilseed meals is given in Table 9. Soya beans were readily available throughout the course of the project and were of consistent

quality, however the price rose sharply in 1986 (see Table 10). They provided substantial quantities of crude protein (40 - 50% depending on the processing method [see chapter 5]) with relatively high levels of lysine, however the methionine content (0.2% of protein) of the analysed sample was rather poor compared to published figures (1.4% of protein) given by Gohl (1981). Tacon *et al* (1983) were able to reduce the fish meal content of a feed for Rainbow Trout from 35% to 10%, by replacing it with various forms of soya beans, without any diminution in growth. Interestingly they found no significant difference in fish growth between those fed feeds containing the different soyabean products, including toasted full fat soya bean meal and hexane extracted soya bean meal.

Cottonseed was not used for long in the feeds because of problems with the screw presses (see Chapter 5). The result of proximate analysis of one sample of cottonseed oilcake (Table 9) shows that it contained high levels of fats, fibre and ash, giving a correspondingly low crude protein level. The high ash content suggests contamination of the cottonseed with inorganic material. Published results from other sources (Gohl, 1981) indicate that well processed cottonseed cake can be used to supply useful quantities of protein, with crude protein levels up to 47%, however this can only be achieved if the seeds are dehulled before oil extraction.

Sunflower oilcake was of consistent quality, however the results of amino acid analysis indicate that the sample analysed had much lower essential amino acid levels than those published elsewhere (Gohl, 1981). Sunflower oilcake was easy to use as it required no further processing before incorporation into the feeds.

Oilseeds and oilseed cakes were regularly used to provide the bulk of protein in the tilapia feeds. Inclusion rates in the feeds varied between 20 to 30%.

4.6. High carbohydrate ingredients.

As discussed in chapter 1, carbohydrates are often the cheapest form of energy in tilapia feeds. An adequate supply can spare the use of protein for energy production.

The main carbohydrate source used at the Nakambala Tilapia Farm in 1983 and 1984 was Maize. This was because it was produced at Nakambala and so was easily available. Its use was discontinued in 1984 in preference for wheatings which, although this product had to be bought in, were much cheaper (see Table 10), gave a lighter, slower sinking pellet and contained higher crude protein levels (see Table 9). Maize has also been reported to contain phytic acid which has been shown to bind zinc, manganese and copper, making them unavailable in feeds (Jauncey, pers. comm.).

Wheatings were available as a byproduct of white flour production from the National Milling Company in Lusaka. Although some wheat was grown in Zambia, most had to be imported. It was generally imported as whole wheat and milled in Zambia. Wheatings was readily available as long as there was enough foreign exchange for the country to import wheat. With the decline in the intensive livestock production industry the millers often had difficulty in selling the wheatings so the price remained stable over the years (Table 10). Inclusion rates used in the feeds were between 30 and 45%. At these levels the resultant pellets were of reasonably hard consistency but light enough for them to sink slowly in the water, allowing the fish more time to pick the pellets up in the water column. Proximate analysis showed that wheatings contained higher protein levels than other high carbohydrate materials (Table 9), however amino acid analysis showed lower essential amino acid levels than those published elsewhere (Gohl, 1981).

Sorghum was used in one feed trial as it was being grown on the sugar estate and was cheaper than maize. Its use was discounted because it was still considerably more expensive than wheatings and it produced a very dense pellet. Proximate analysis (Table 9) showed it to be nutritionally similar to maize, however amino acid analysis showed that it contained higher levels of essential amino acids than those published elsewhere (Gohl, 1981), with particularly high levels of methionine and phenylalanine.

For a period in 1985 and early 1986, wheatings became totally unavailable. All Zambian produced wheat had been used up and there was no foreign exchange available for importation. A reasonably priced alternative to wheatings had to be found. Each crop the sugar factory produced about 150000 tonnes of bagasse, the residue of cane stalks after extraction of sugar. Most of this was used to run boilers which, through steam turbines, produced all the energy required to run the factory. There was usually a surplus of bagasse, the extent of which depended on the fibre content of the sugar cane. Bagasse is very fibrous and not very digestible. Another byproduct of the sugar factory was molasses. This contains the carbohydrates left behind after sucrose has been extracted from raw cane juice. The sugar factory often had problems in selling molasses because of difficulties in distribution to farmers who would use it in cattle feeds. Bagasse can absorb large quantities of molasses to form a solid product which can be handled, mixed and pelleted like any other high carbohydrate material (Gohl, 1981). Because of the bulky nature of bagasse and its high moisture content as it left the mill (40%), it was found that the easiest way to handle it was to mix at a ratio of 1:3, bagasse:molasses by dry weight, sun dry and pellet using a large die (8mm). This made storage of the bagasse/molasses mixture easy. The pellets were then used at inclusion rates of up to 45% in production diets. Table 9 shows that the protein content was very low, as would be expected. The analysed nutrient levels are similar to those reported by Gohl (1981) in commercial bagasse/molasses mixes.

4.7. High vitamin content ingredients.

Complete vitamin premixes such as those recommended by Jauncey and Ross (1982) could not be provided on a regular basis in production feeds because of the lack of foreign exchange for their importation. Ocasionally vitamin premixes were available within Zambia and were used in the feeds. Multivit P (Assia Maabarot Ltd, Tel Aviv, Israel) was formulated for chickens and contained high levels of vitamin A (15000000 I.U./kg), no vitamin B1, vitamin B6, vitamin C, folic acid, biotin or inositol, but did contain an antibiotic (procaine penicillin). Nutramix AIF (Hoescht Ltd.) was formulated for pigs. This contained a wider range of vitamins but still did not have vitamin C. The vitamin contents were quite different from those recommended by the University of Stirling, the mixes were expensive and not always available. In an attempt to alleviate possible vitamin deficiencies a number of feed ingredients were included in the feeds principally for their high contents of particular vitamins.

Leucaena is a leguminous shrub which is widely used in the Tropics as fodder for cattle. It suits the Zambian climate as it can grow through the dry season without irrigation. As well as reasonably high protein levels in the leaves, leucaena contains high levels of the fat soluble vitamins (Nurse and Thorp, 1981; Wood and Carter, 1983). Leucaena meal became available at Nakambala in 1985 because a neighbouring farmer allowed the fish farm to have access to a plot of 5 hectares which he had established for feeding cattle. In late 1985 a plot was established close to the fish farm. The leucaena was harvested by cutting off the small twigs and leaves, sun drying then milling and bagging for storage. The maximum inclusion rate used was 10%. Results of feed analysis are shown in Table 9. The protein content of leucaena meal varied from 13 - 29% (average 22.8%) according to the proportion of leaves to twigs. Nurse and Thorp (1981) suggested protein levels of 20 - 25% for ungraded leucaena leaves, whilst N.R.C. (1983) report a protein content of 29.1% of dry matter.

Lucerne is another leguminous crop grown for cattle feeding. It grows as a small plant and must be continuously irrigated. A small plot was established near the fish farm in late 1985. Lucerne was harvested periodically by hand, sun dried and milled before use. The composition of the lucerne varied with the age of the plant (See Table 9). Younger lucerne had a much higher protein content but also a higher moisture content and lower yield. Generally the lucerne used in the feeds was 3 weeks old. Lucerne has been reported to contain high levels of fat soluble vitamins, particularly vitamins A and D (Gohl, 1981).

Yeast contains high levels of water soluble vitamins, particularly vitamin B1 (99mg/kg), vitamin B2 (38mg/kg), vitamin B6 (40mg/kg) and vitamin B12 (1.0mg/kg) and is often used as a source of B complex vitamins in poultry and pig rations (Gohl, 1981; N.R.C., 1983). Small amounts of yeast floor sweepings were available from time to time from the Lee Yeast Co. Ltd. of Kafue. The yeast was *Saccharomycescereviciae* grown on a mollasses substrate to be sold to bakers as live yeast and as active dried yeast. The floor sweepings resulted from the production of the active dried yeast. Proximate analysis of the yeast is shown in Table 9. This shows that it contained high crude protein levels. Amino acid analyses reported by Gohl (1981) and N.R.C. (1983), show that the balance of amino acids is good, with relatively high lysine levels. Attempts were made to grow yeast specifically for use in the fish feeds at Nakambala using simple methods. The yeast was grown in a 100 litre plastic drum containing diluted molasses(1:4; molasses:water) and a small amount of fertiliser (urea and triple super phosphate). The drum was inoculated with a live yeast culture and air bubbled through the culture. There seemed to be no problem growing the yeast, but harvesting was difficult without a centrifuge. A flocculant strain of yeast was provided by Tate and Lyle Research And Development but this characteristic was not maintained, probably due to contamination with wild yeasts.

4.8. Algae

The culture, harvesting and processing of algae is described in Chapter 6.

CHAPTER 5. FEED PROCESSING METHODS AND EQUIPMENT.

5.1. Introduction.

Although many different processes were used in the manufacture of fish feeds at Nakambala Tilapia Farm, they could all be grouped into one of four basic processes; pretreatment, milling, mixing and pelleting. The system is illustrated in Figure 5.

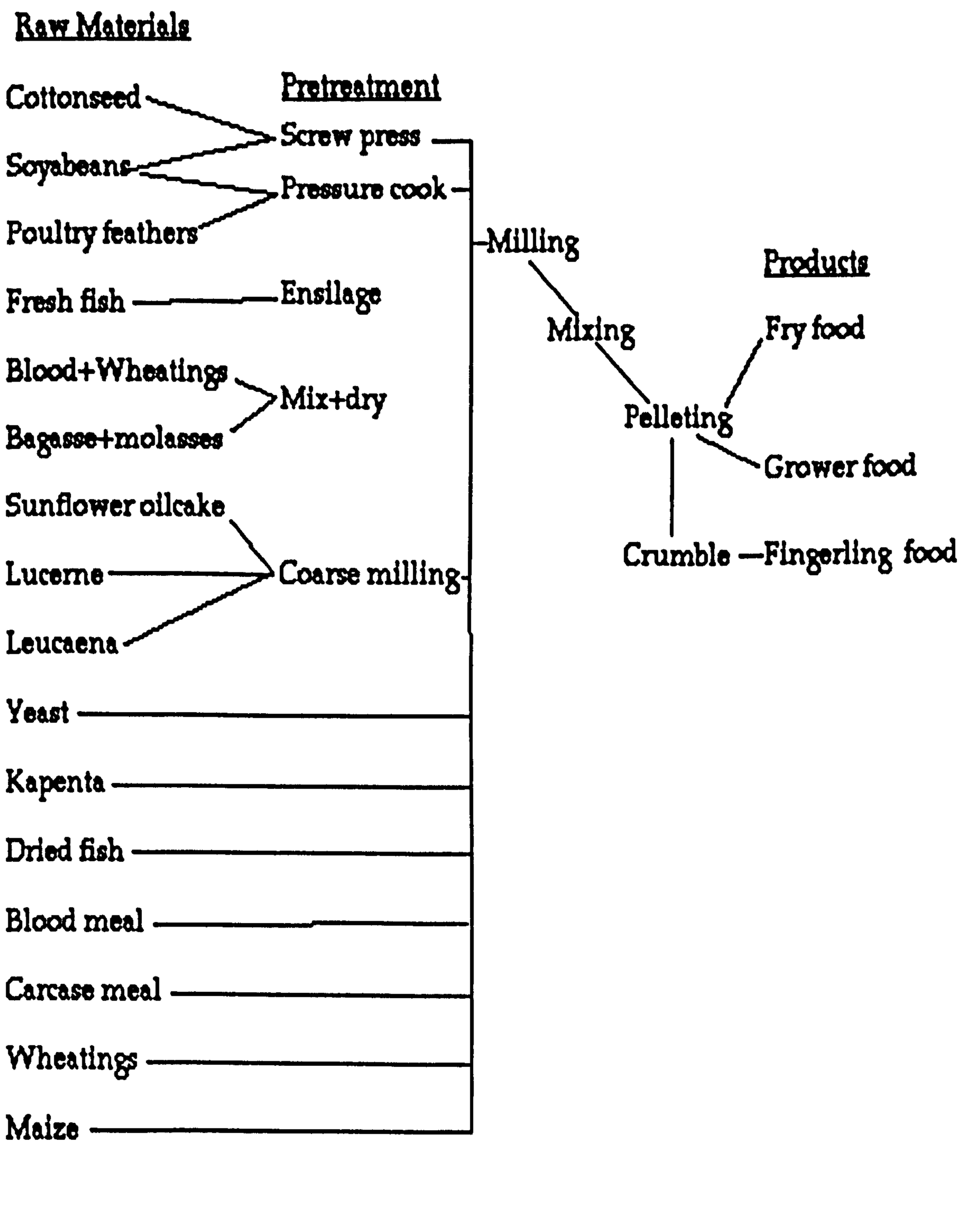
Pretreatment was necessary for some of the ingredients for a variety of reasons. Raw oilseeds contain antinutritional factors which must be deactivated before use. Raw fish caught in irrigation dams had to be processed so that they could be stored before use in the feeds. Some of the materials were very bulky so pretreatment was necessary to facilitate storage.

Milling is an important part of the process as it determines the particle size within the pellets. As well as affecting the consistency of the pellets this can have a great effect on the digestibility of some of the ingredients (Payne, 1978).

Adequate mixing is an essential step as it determines the uniformity of pellets within a particular feed batch.

Pelleting forms discrete feed particles which can be taken up by the fish without waste or dirtying of the water. This is most important in intensive culture.

Figure 7. The feed processing system at Nakambala.

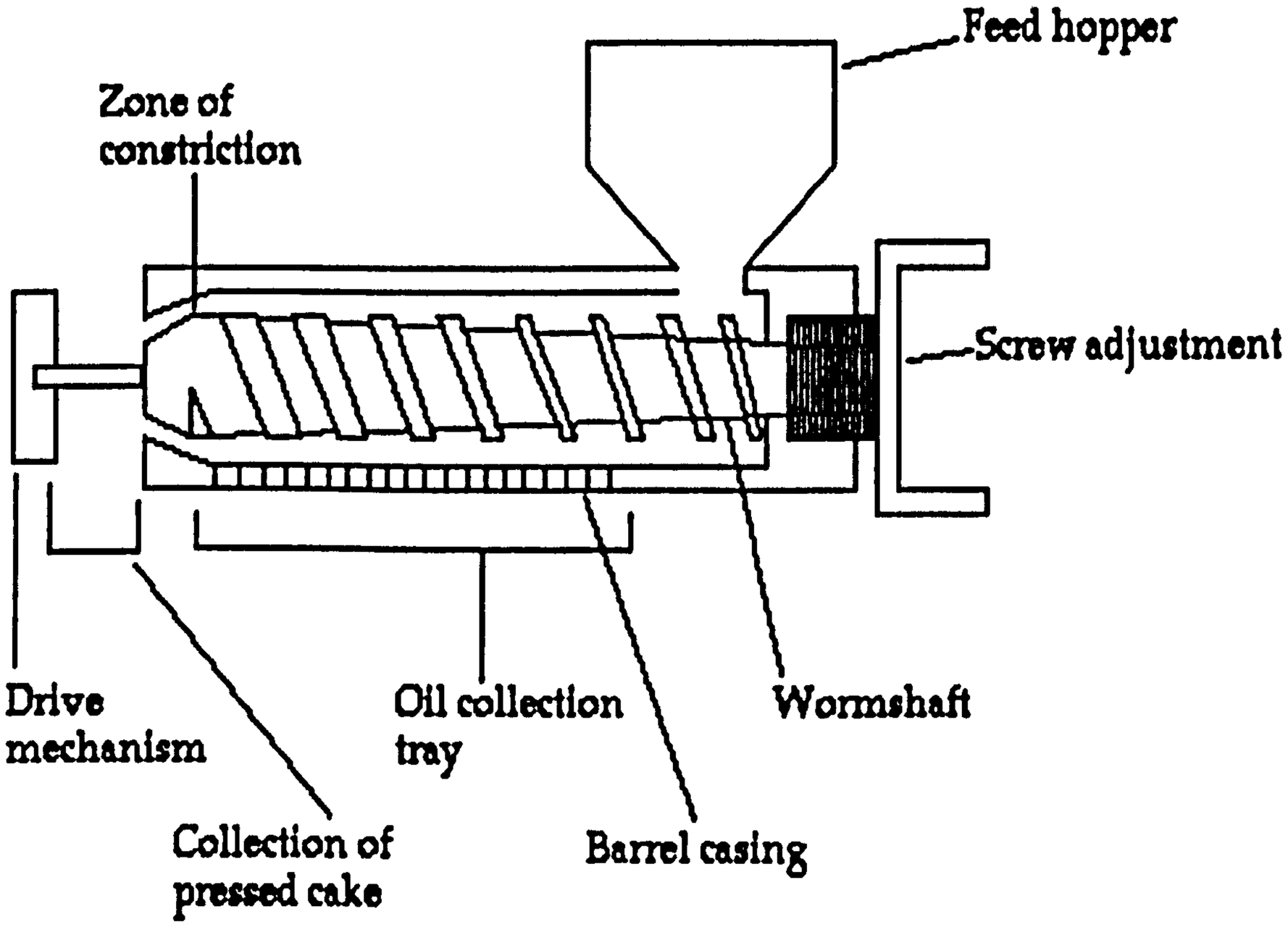


5.2 Screw Presses.

Screw presses were used at the start of the project to pretreat raw oilseeds, in particular soyabeans and cottonseed. The main objective was to deactivate the antinutritional factors, any oil extracted in the process was secondary to this. The principal factors which are recognised as important in the nutrition of other animals are trypsin inhibitor in raw soyabeans and gossypol in raw cottonseed (Gohl, 1981).The principal of operation of a screw press is illustrated in Figure 8. Material to be processed is fed into one end of a revolving screw or worm which is enclosed in a casing with slits or holes in it. The screw is tapered so that the volume occupied by the feed material is gradually decreased towards the end of the screw. This causes an increase in pressure and temperature due to friction, rupturing the cells in the feed material and forcing any liquid present, such as oil, through the slits in the casing. The pressed material is expelled at the end of the screw having been partially cooked and with a reduced oil content. Although these machines are usually used for the small-scale production of edible oils, our main priority was to deactivate the antinutritional factors. Any oil produced was sold to the estate kitchens.

Two presses were used. The first was a screw press manufactured in China which was bought second hand from an agricultural machinery importing company. It had been used as a demonstration model and was well worn when purchased by the fish farm. This press was fitted with a 5kw electric motor driving the wormshaft through a series of metal cogwheels. The slits in the casing around the wormshaft were formed by tightly packed stainless steel bars running along the same axis as the wormshaft. The second press was imported new from England. The model was a Simon Rosedowns Mini 40 driven by a 2.2kw electric motor through a belt drive system to the wormshaft. In this machine the slots around the wormshaft were formed by barrel rings held tightly together but spaced by thin washers.

Figure 8. Screw press.



Both machines displayed individual characteristics and took some skill in their operation. The Chinese machine was very noisy due to the mechanical drive system. Both machines performed adequately for a period after they had been "run in", however both suffered greatly from wear on the wormshaft and casings, greatly reducing their effectiveness. Throughput rates of materials varied from 5 - 30kg/hr depending on their mechanical state. The effective working life of a new wormshaft and barrel casing was about two tonnes for both machines, at which time new or reconditioned parts had to be fitted for the machines to operate at all. Usually soyabeans had to be passed through the machine at least twice before they acquired the "nutty" taste indicating that they have been cooked enough to deactivate the trypsin inhibitor (Gohl, 1981).

After struggling to keep the screw presses operating by renovating the parts in the factory workshop because spare parts could not be imported, the process was abandoned for both soyabeans and cottonseed in April 1985. It was decided that a more appropriate method of pretreatment would have to be used if oilseeds were to be used in the feeds.

5.3. Pressure Cooker.

After the abandonment of screw pressing for the pretreatment of soyabeans and cottonseed, other processes were used on an experimental basis to cook soyabeans. A heated rotating drum constructed from an oildrum gave uneven cooking and charring of some of the seeds. A percolating cooker(see Figure 9) gave even cooking but resulted in the seeds having a high moisture content. They had to be dried before they could be used in the feeds.

Figure 9. Percolating cooker.

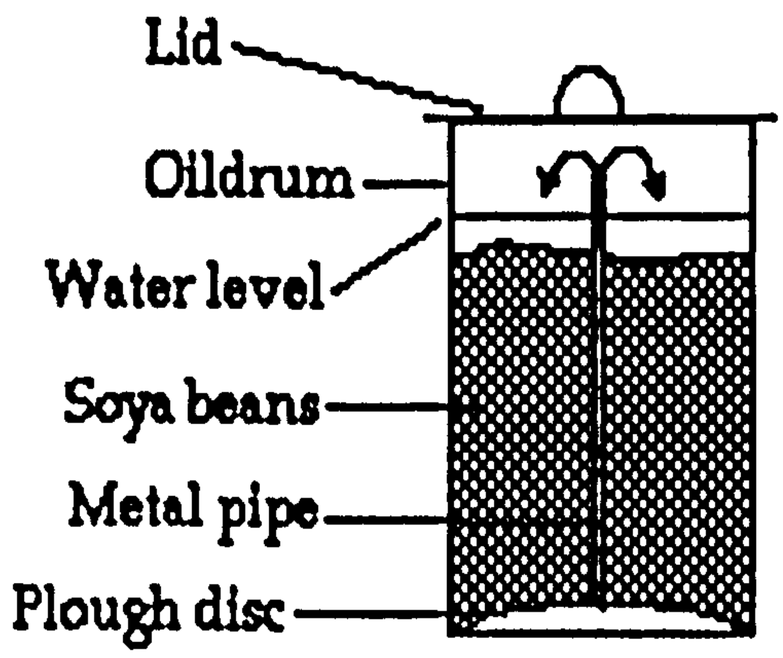
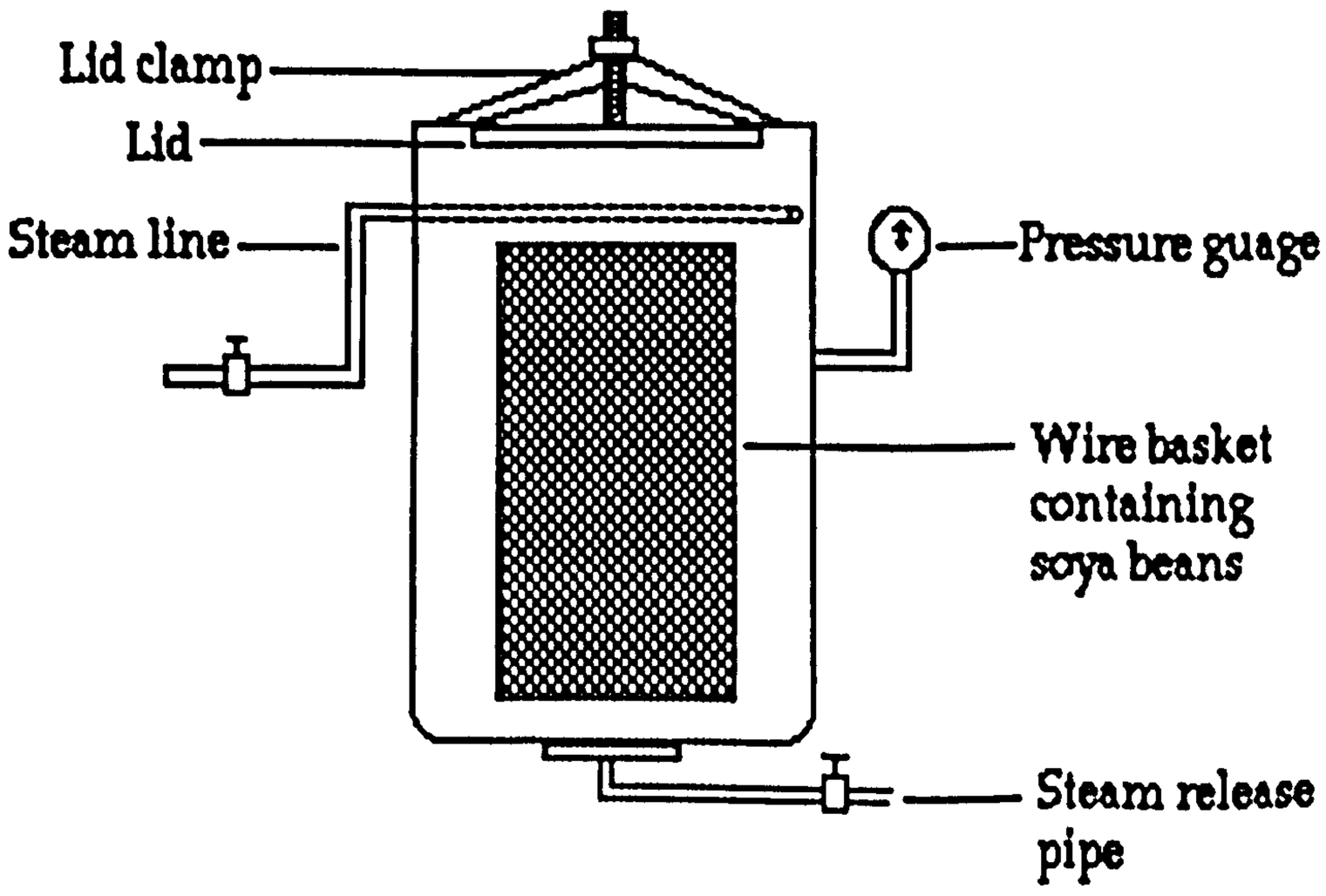


Figure 10. Pressure cooker.



A pressure cooker constructed in the sugar factory workshop, from a garage air receiver vessel, was introduced in September 1985. The cooker was designed in conjunction with some of the factory engineers at Nakambala. Figure 10 shows the construction of the pressure cooker. It was operated from a steam line running from a wood fired boiler situated in the kitchens which were adjacent to the fish farm. The cooker was operated by filling a wire basket with beans(45kg/batch), lowering the basket into the cooker and closing the lid, ensuring that the sealing gasket on the lid was in position. Steam was them applied to the beans by opening the valve leading to the boiler. The steam was allowed to pass through the vessel by leaving the steam release valve open at the bottom of the vessel, until air was expelled and any water due to condensation was discharged. The release valve was then closed and the vessel allowed to pressurise. The cooking temperature was gauged by the pressure in the vessel. Pressure was controlled by adjusting the inlet valve. Various cooking regimes were experimented with, but it was found that the minimum cooking period for the beans to taste "nutty" rather than "beany" (see section 5.2) was one bar of pressure for 15 minutes. This is similar to the cooking period recommended by Gohl (1981). The advantages which this process had over screw pressing for soya beans were that the process was fast, cheap (steam was free), easy to operate, maintainence free and gave reliable cooking of the beans. The beans were evenly cooked and absorbed little moisture. In one test the moisture content of pressure cooked soyabeans immediately after being removed from the cooker was 12.3%. After 24 hours sun drying the moisture content had reduced to 4.9%.

A second pressure cooker of similar design was built in late 1985 for the cooking of chicken feathers to produce hydrolysed feather meal. Early attempts to produce hydrolysed feather meal were carried out in a very basic pressure vessel set over a wood fire. The vessel was sealed by rubber "O" rings which eventually degraded with heat making it difficult to achieve the correct pressure. Production of hydrolysed

feather meal requires more extreme treatment than for soyabeans. The treatment used was based on the method recommended in Gohl (1981) of 145°C for 30 minutes. Thirty minutes at a pressure of 3 bar gave a product which was obviously cooked, as it did not contain raw feathers, but was not charred. The product was relatively easily dried (1 - 2 days sun drying) and easily milled. The second pressure cooker for hydrolysed feather meal production was installed at the premises of Zambia Pork and Poultry Ltd in Lusaka, running off an electric boiler. The intention was for Z.A.P.P. to carry out the processing and drying so that they could sell the hydrolysed feather meal to the fish farm at an agreed price. The arrangement never really worked, mainly due to a lack of enthusiasm by Z.A.P.P, but also because of a decline in the poultry industry leading to a shortage of chicken feathers to be processed.

5.4. Ensilage.

The most widely used source of animal protein in aquaculture feeds is fish, however it is usual for this to be processed in some way prior to incorporation in a feed as raw fish cannot be stored for any length of time without spoiling (Shewan, 1976). The simplest form of processing is drying. This is often used in Zambia for fish for human consumption. It suffers from a number of drawbacks. If it is carried out in the open air, the rate of drying depends totally on the prevailing weather. Any delay in drying leaves the fish very susceptible to attack from insects and fungi which can leave little more than skin and bones in a very short period of time.

A more acceptable process for the preservation of fish for animal feeds is the production of fish meal. In this the fresh fish is cooked, any excess fat is removed and the solids are dried to produce a uniform meal which can be easily milled, bagged and stored. Fish meal production is expensive and can usually only be used where there are substantial stocks of fish to put through the plant (Disney, Tatterson and Olley, 1976). At Nakambala, small quantities of fresh fish were available on an occasional basis for inclusion in the fish feeds. In addition culled fish, mortalities and gutting wastes were other sources of fish protein which were available.

It was decided that the production of fish silage was a technology which might allow the supplies of fish protein to be used in an hygienic way. Two main methods have been described for the production of fish silage. Acid silage is produced by the addition of organic or inorganic acids to minced fish. Gohl (1981) suggests the addition of about 5% concentrated acid. Wood *et al* (1985) used 3% w/w formic acid to ensile minced, whole whiting. Raa and Gildberg (1982) suggest the use of between 2.8 and 6.3% w/w sulphuric acid, depending on the oil content of the fish. The object is to depress the pH of the minced fish to 4 or below so that it is protected from degradative bacteria and fungi. The low pH also allows the digestive enzymes of the fish to break down the tissues into a liquid, which is easily handled.

Because of the foreign exchange requirement needed to secure regular supplies of acids, it was decided that the production of fish carbohydrate silage was more appropriate. This process has been described by a number of authors (Raa and Gildberg, 1982; James *et al*, 1976; Gohl, 1981). The principle is to use the anaerobic fermentation of bacteria on a carbohydrate source, added to the minced fish, to produce lactic acid. The lactic acid, lowers the pH of the silage and acts as a preservative. The process is similar to that used for the production of fodder silages,

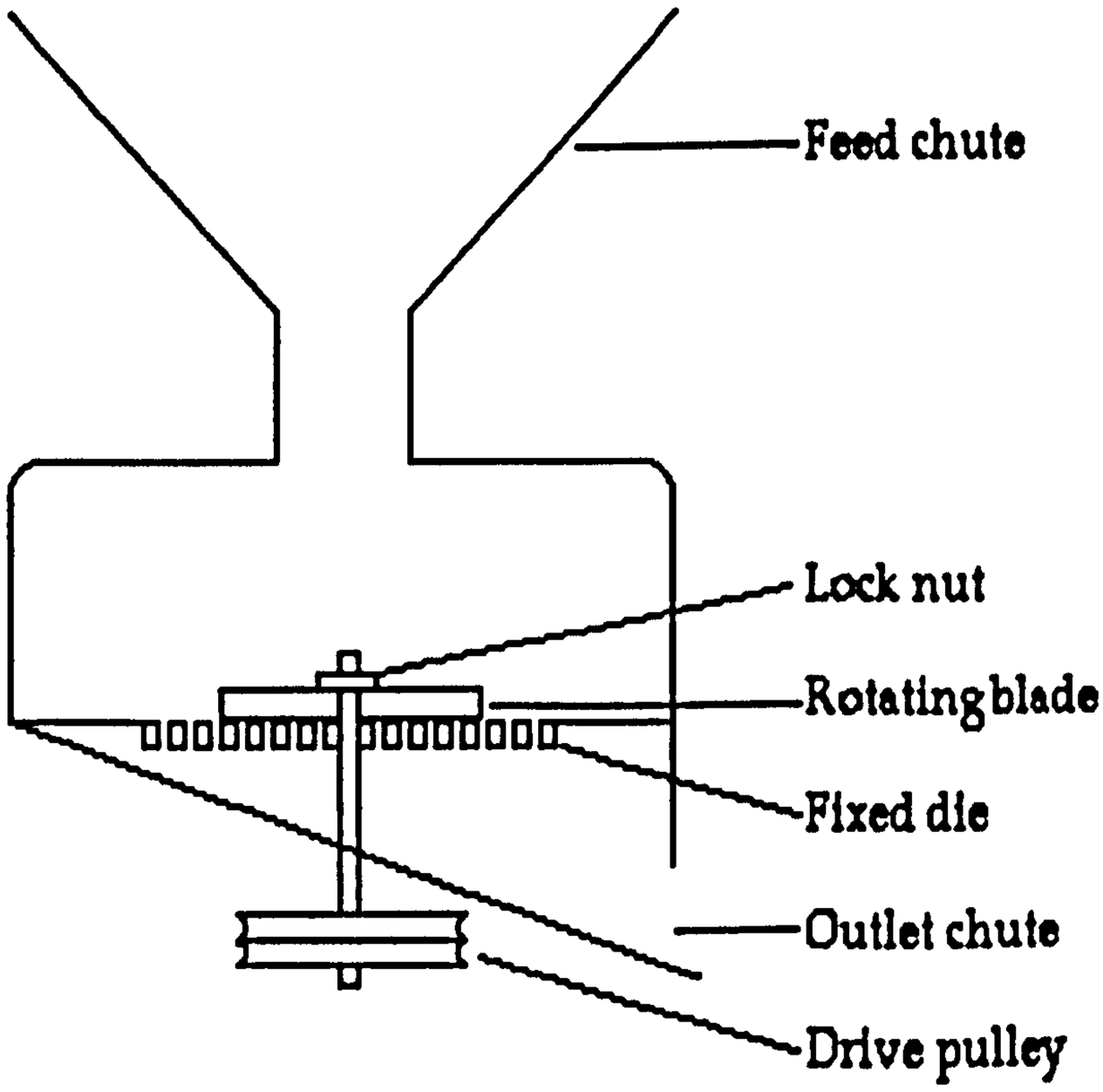
exceptthat the low carbohydrate content of fish means that a substrate for bacterial growth must be added.

The range of substrates used is varied, however the most easily available source at Nakambala was molasses. James *et al* (1976) described experiments in which silage was made from minced fish, 15% by weight of molasses and 30% by weight of water. A starter culture of *Lactobacillus plantarum* was also added. A pH of 4 to 4.5 was attained after 72 hours, to produce an acceptable silage.

There are a number of bacterial species important in lactic acid silages. They are generally grouped into the homofermenters, such as *L plantarum*, which produce only lactic acid from a glucose substrate, and the heterofermenters, such as *Leuconostocspp*and *Streptococcusspp* which produce acetic acid, carbon dioxide and ethanol in addition to lactic acid. At the start of a culture, as the pH is dropping, the heterofermenters can predominate, to be replaced later by the homofermenters (Raa and Gildberg, 1982).

At Nakambala, a working system was developed after a number of trials. The raw fish were minced in a machine fabricated in the factory workshop (see figure 11), and hand fed into 100 litre capacity plastic drums with sealable lids. The drums were filled almost to the top, weighed and 10% by weight of molasses added. The drums were them thoroughly mixed, sealed and allowed to stand. It was found that considerable quantities of gas were often produced in the first few days (probably carbon dioxide due to the action of heterofermentataive bacteria). Each day the drums were remixed and any accumulated gas released. If the gas was not released the drums could explode. Gas evolution usually stopped after 3 - 4 days, by which time the pH was 5+/-0.2, and the silage was beginning to liquify. Batches of fish silage maintained a pleasant smell, even after storage for six months.

Figure 11. Fish Mincer.



The silage was mixed with maize or wheatings in the horizontal mixer, prior to mixing with other feed ingredients and milling. Use was restricted to 5% of the dry weight of the feed because of the high moisture content of the fish silage (72%). Higher inclusion rates made the moisture content of the feed mix too high, which caused blockages in the hammer mill and pelleter.

The process was discontinued in April 1985 because of a shortage of fish to be ensiled and the increasing availability of other, more convenient, high protein feed ingredients.

5.5. Milling and Mixing.

A hammer mill was used for all the milling operations. The mill was a Fodder Mill manufactured by All Metal Engineering of Kitwe, Zambia. It was powered by a 50 horse power electric motor and had swinging hammers. It was supplied with a variety of screens. Throughput rates of the mill varied greatly depending on the material being milled and the screen used.

Large screens with apertures of 10 - 20 mm were used to premill some of the feed ingredients. This was carried out for a number of reasons. Dry lucerne and leucaena were premilled to aid storage. The coarsely milled materials could be easily bagged and stored in a compact space. Sunflower oilcake supplied by Chemical Products of Lusaka had to be milled with a coarse screen as the dense lumps of material would have damaged the lighter screens used for fine milling. Throughput rates for coarse milling were fast and depended more on the rate at which the materials could be supplied to the mill than on the mill itself.

After all the feed ingredients were in a form which could be finely milled, they were weighed out, according to the formulations provided, into a mixing trough. The ingredients were then coarsely mixed using a shovel and fed by hand onto the feed tray of the hammer mill. The screen used in the hammer mill for fine milling had apertures of 1mm. Normal feed formulations could be milled at a rate of 50 - 80kg/hour. Formulations with higher oil or moisture contents caused greatly reduced milling rates or sometimes even complete screen blockages. The output from the hammer mill was into bags attached to a cyclone. Air escaped from the cyclone into a pipe which passed through the roof of the building, to reduce the amount of dust in the feed processing room. Some of the lighter food particles were also blown out of the pipe. Expensive, fine ingredients such as vitamin premixes were not added to the feed until the mixer in case they might be lost during milling.

Each batch of milled meal was then fed into a horizontal mixer and mixed for 20 minutes. The mixer was manufactured by W.L.Holland of Preston, England and supplied by Lister Farm Equipment. Mixing was effected by ribbon type paddles attached to a central shaft rotating at 30 r.p.m. and driven by a 3 kw motor. The effective working volume of the mixer was 376 litres, which determined the maximum size of each batch of feed. This varied from 75 - 150 kg depending on the feed formulation used. Formulations containing high levels of bulky materials such as wheatings had to be processed in smaller batches than those containing maize or sorghum.

5.6. Pelleting, bagging and storage.

The mixed food was carried by mechanical auger from the mixer into a hopper leading to the pelleter (Lister Farm Pelleter - 7.5kw electric motor). Feed of the material from the hopper was by gravity and there was no water addition or steam conditioning applied. The pelleter had to be constantly attended as the feed supply could be interrupted by bridging of the meal in the hopper. Pelleting rates varied with the die size, die condition and the feed formulation. For normal dry production feeds and a 4mm die the usual rate was 75 - 100 kg/hour. High moisture contents (above 15%) or high oil contents (above 10%) resulted in die blockages. This usually meant that the die had to be removed, and each hole punched out with a metal rod, before it could be reused. The main problems which arose with the pelleter, resulted from wear on the pelleting dies and rollers. The initial dies supplied with the machine only lasted for a few tonnes because the feeds contained kapenta contaminated with sand. The dies were expensive to replace. Subsequent dies lasted for around 100 tonnes of production.

Most reports on feed manufacture stress the need for steam conditioning of meals prior to pelletisation to increase gelatinisation of starch and produce a stronger pellet (Wood, 1980; Payne, 1978; MacBain, 1966). A hard pellet may be more water stable, however tilapias in intensive culture, tend to prefer a relatively soft pellet (Dickson, 1981). When presented with a hard pellet, the fish tend to spit it out, whereas a softer pellet is eaten directly. Other factors affect the hardness of pellets, particularly the type of high carbohydrate feed ingredient used. Maize and sorghum gave hard, dense pellets. Wheatings and Bagasse/molasses yielded softer, less dense, pellets.

Pellets, leaving the pelleter at temperatures of 70 - 80°C, were lifted by a mechanical bucket elevator into a cooling hopper.The cooling hopper was fitted with a fan designed to blow air over the pellets to reduce the moisture content before bagging. As no water was added to the formulations, and the fan created a lot of dust, it was not usually operated. The hopper acted as a convenient point between pelleting and bagging at which to let the pellets cool down. The pellets were fed into hessian sacks after cooling, and stored, if not used immediately. Feeds were usually made as required, so storage of prepared feed was rarely for more than one week. This reduced the risk of the feed being contaminated with mycotoxins (Jones, 1974).

5.7. Feed formulation and record of feed manufacture.

Table 11 shows some of the formulations used over the course of the project. Up to three formulations were manufactured at any time to cope with the varying demands of the different sizes of fish on the farm. Fry food was fed to fish of up to two grammes weight. It was manufactured by milling and mixing the ingredients. No pelleting was carried out. Fingerling food was used for fish from two to thirty grammes in size. This was pelleted and then crumbled using a hand grinder to particles of 1 to 3mm diameter. Grower food was pelleted using a 4mm die and fed to fish of over thirty grammes in weight.

Feed formulations were worked out by hand using trial and error. Information on the available feed ingredients was collated and, if analysis of a particular feed ingredient had not been carried out, the data was taken from published sources (Gohl, 1981; N.R.C, 1983). Formulations aimed to supply the nutrient levels suggested in Table 2. The main parameter used in formulation was the crude protein content, however

Table 11. Examples of formulations used at Nakambala Tilapia Farm (Expressed as %ages of dry ingredients as fed).

	Fingerling			1/86 - 7/86			7/86 -	
	1983	1984	1985	Fry	Fing.	Grower	Fing.	Grower
Fish Silage	5	5	4	-	-	-	-	-
Kapenta	5	-	10	15	12	8	8.5	5.5
Blood(Dried)	-	5	4	-	-	-	-	-
Blood Meal	-	-	-	15	12	8	17	11
H.Feather Meal	-	5	-	-	-	-	-	-
Soya Oilcake	30	10	13	-	-	-	-	-
Full Fat Soya	-	-	-	20	27	13	29	14
Sunflower oilcake	-	10	13	-	13	13	14	14
Cottonseed oilcake	-	10	-	-	-	-	-	-
Maize	60	20	-	-	-	-	-	-
Wheatings	-	30	-	-	10	14	21	45
Bagasse/Molasses	-	-	43	-	10	30	-	-
Leucaena	-	-	10	-	-	-	5	5
Lucerne	-	-	-	20	10	10	5.5	5.5
Yeast	-	-	2	30	6	4	-	-
Algae	-	4.8	-	-	-	-	-	-
Vitamin Mix*	0.2	0.2	1	-	-	-	-	-

* Various vitamin premixes were used when available.

later in the project, some of the materials (leucaena, lucerne and yeast) were automatically included at set levels for their vitamin content. A formulation would be guessed at and the contributions each ingredient would make to each of the main nutrients, tabulated and added up. If the formulation did not supply the nutrient levels required, adjustments were made to the formulation and the information retabulated.Formulations developed as the project progressed.

Table 12 shows the results of nutritional analysis of the feeds over the course of the project. This shows that as the project progressed the formulations came closer to matching the Stirling recommendations, at least with respect to the major nutrients. Amino acid analysis indicated that the feeds were still deficient in methionine at the end of the project. Following extensive feed trials it was decided that there was no requirement for vitamin or mineral premixes in the diets (see chapter 7).

As the project developed, a wider range of feed ingredients became available. This allowed some of the more unsatisfactory or awkward ingredients such as fish silage and raw blood, to be replaced with more easily handled ingredients such as blood meal and kapenta. Shortages of ingredients were commonplace, so formulations had to be flexible. Most feed materials could be substituted with another. If, for example, sunflower oilcake became unavailable it was substituted with another oilseed, usually soyabeans. If blood meal could not be obtained it was replaced with kapenta. Whilst formulations were changed to compensate for the differences in nutrient levels between substituted ingredients, this undoubtedly caused fluctuations in the overall nutrient composition of the feeds. Making do with what was available was the only strategy which could be used to keep the feed mill running.

Table 12. Nutritional analysis of production feeds. I. PROXIMATE ANALYSIS: Crude Protein, Ether Extract, Crude Fibre and Ash expressed as %age of moisture free weight in feed; Moisture expressed as %age of feed as fed. (Figures in parentheses represent the number of samples contributing to each average).

	Moisture	Crude Protein	Ether Extract	Crude Fibre	Ash
1983 - Fingerling	N.D.	25.6(3)	7.0(3)	6.9(3)	4.7(3)
1984 - Fry	12.5(1)	30.5(3)	5.3(3)	15.6(2)	14.7(3)
- Fingerling	8.5(1)	28.9(3)	7.6(3)	17.3(2)	7.1(3)
1985 - Fry	10.3(20)	35.0(21)	6.1(1)	N.D.	8.3(20)
- Fingerling	10.4(25)	31.5(26)	4.7(1)	N.D.	9.0(25)
- Grower	9.6(7)	27.5(7)	N.D.	N.D.	9.2(7)
1986 - Fry	9.4(9)	40.1(9)	8.2(3)	10.1(2)	14.8(9)
- Fingerling	9.3(10)	32.0(10)	11.0(4)	11.3(2)	9.0(10)
- Grower	10.0(9)	25.5(9)	8.8(3)	10.1(2)	8.3(9)

N.D. = Not determined

II. AMINO ACID ANALYSIS: Amino acid levels expressed as %age of crude protein content in each sample*.(Analyses carried out by the Inst. of Aquaculture, Univ. of Stirling.)

	ARG	HIST	ISOL	LEU	LYS	METH	PHE	THR	TYR	VAL
Fingerling Food	6.1	2.7	6.9	11.3	6.0	0.3	4.5	3.9	2.3	5.4
Grower Food	5.3	2.5	7.3	11.3	4.9	0.5	3.8	3.4	1.7	4.6

ARG = Arginine, HIST = Histidine, ISOL = Isoleucine, LEU = Leucine, LYS = Lysine, METH = Methionine, PHE = Phenylalanine, THR = Threonine, TYR = Tyrosine, VAL = Valine.

*Results are from single samples of each taken on 1/9/86. Grower food contained 27.6% Crude Protein. Fingerling food contained 25.8% Crude Protein.

Table 13 shows the quantities of feed manufactured in each year of operation. Feed was made as required, so the quantities produced reflect the increasing quantities of fish produced on the farm. An indication of the approximate cost of the feed raw materials per tonne of feed produced is also given in Table 13. This shows the effect of inflation in the Zambian economy, rather than changes in formulations, on the feed cost. The rise in costs was passed on to the selling price of the fish.

Table 13. Quantities and cost of raw materials of feed manufactured.

Year Ending	Quantity of Feed Produced(Kg)	Cost of Feed Raw Materials/Tonne of Feed(ZK)	Average Selling Price for Fish(ZK/Kg)
31/3/83	8415	N/A	3.02
31/3/84	37658	N/A	5.29
31/3/85	66115	459	3.63
31/3/86	87993	799	5.42
31/3/87	102640	1178	7.19

N/A - not available

CHAPTER 6. ALGAE CULTURE.

6.1. Introduction.

Algal culture has been put forward since the 1940's as a possible means of supplying protein for animal or human food (Jorgensen, 1953; Edwards *et al*,1981). Other uses have been proposed including algal culture for wastewater reclamation (Oswald, 1969; De Pauw *et al* 1980; Wong and Lay, 1980), algal culture producing biomass for further processing as a chemical feedstock (Tate and Lyle, unpublished data) and the culturing of algae for gaseous exchange in space operations (Shelef *et al* 1969). Some advantages which algae have over conventional protein sources are that they are primary producers, able to convert simple molecules such as carbon dioxide and inorganic nitrogen into complex proteins, the level of protein is higher in microalgae than in most other primary producers and being in a liquid form allows easy handling of the product. The principal disadvantage is that the harvesting of algae, particularly microalgae, is difficult because of the small size of the algal cells.

Despite the considerable optimism expressed over the years (Benemann *et al* 1977), and apart from a few specialised applications such as the culture of marine microalgae for marine fish larvae, the production of algae tablets for the health food market and the occasional use for wastewater treatment, there are few economically viable algae culture operations in the world today (Goldman, 1979).

During 1980 and 1981 Tate and Lyle Technical Services together with the University of Liege, carried out studies on the culture of algae (Hough, personal communication). Two main approaches were used. The first was the culture of microalgae in a specially

designed culture apparatus which involved trickling a thin layer of the culture solution over inclined glass plates. Whilst growth of the algae was rapid the culture apparatus was very expensive. The constant movement of medium in the algae culture favoured the growth of unicellular algae such as *Scenedesmus spp* The algae were harvested by centrifugation and dried to produce a powder. The second approach was the harvesting of filamentous algae which were growing in the effluent from an intensive tilapia farm using warm water from Tihange nuclear power station. The filamentous algae were separated out by straining and then dried. Algal meals from both sources were analysed and included in feeds fed to tilapias at the University of Stirling. Composition of the algae meals were quite different. Filamentous algae had protein contents of between twenty and thirty per cent whereas unicellular algae had protein levels of up to sixty per cent. Both were shown to support good fish growth (Jauncey, personal communication; Delcambe-Fontaine, 1979). Further work has confirmed that algae can be used as a dietary protein source in tilapia feeds (Appler and Jauncey, 1983).

As a result of this work, it was proposed to supply substantial quantities of algal meals for inclusion into fish feeds at Nakambala Tilapia Farm by culturing algae in the farm effluent. A proposal to this effect was presented by Tate and Lyle to the Overseas Development Administration, who agreed to support a three year research programme into algae culture. This was to be carried out as part of the tilapia farming activities.

6.2. Algae culture system, harvesting equipment and method of operation.

Construction of the Algae Production Unit started in mid 1982. Most of the equipment had to be imported which delayed commissioning of the system until the end of 1982. The system consisted of two 400m^2 ponds together with harvesting machinery. It was

designed by the main equipment supplier, Tim Cox of Sewaco Ltd, however some modifications to his designs were carried out by Courtenay Hough of T.L.T.S. and myself. Figure 12 shows the original layout of the production ponds. Both were lined with 1500 gauge polythene sheeting and were designed to hold a maximum liquid depth of 1.5m. In pond 1 circulation was effected by a submersible pump (DAE-PKD 1150), which pumped water from one end of the pond to the other through a six inch diameter flexible hose. The culture was also aerated using a blower (Wade Engineering Ltd. - Rootes Blower SR035/7.5kw motor) delivering air to 13 aerators (HDPE porous aeration tubing) situated on the bottom of the pond.

In pond 2 both aeration and circulation were carried out by two sets of six coarse bubble aerators (Venturator Ltd. - DF) operated by two blowers (B.V.C. - 2.2kw). The aerators were designed to give directional flow to the water. This pond was divided into a meandering 3 metre wide channel by walls constructed from corrugated asbestos roofing sheets set on their edge and supported by concrete slabs.

After experimentation both ponds were changed to a simplified version of pond 2 as shown in Figure 13. The main reason for the change was to reduce running and capital costs of the system, with the equipment which was available at the time.

The water source for the project was Kafue river water which had passed through the tilapia farm. The nutrient levels in the farm effluent and in Kafue River Water are compared in Table 14. Supplemental fertilisation, when required, was with Urea and Triple Super Phosphate.

Figure 12. The original layout of the Algae ponds

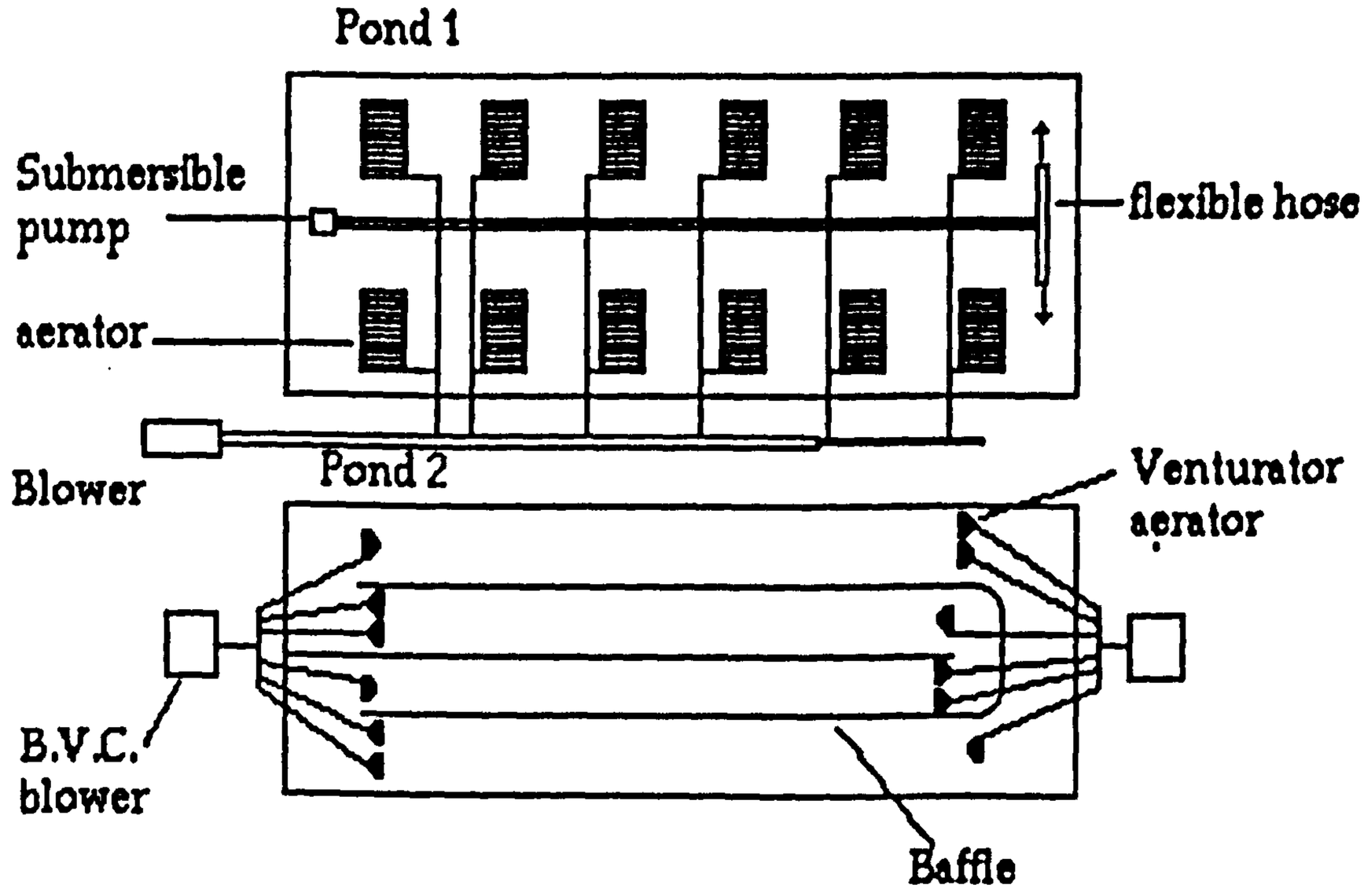


Figure 13. The layout after February 1984.

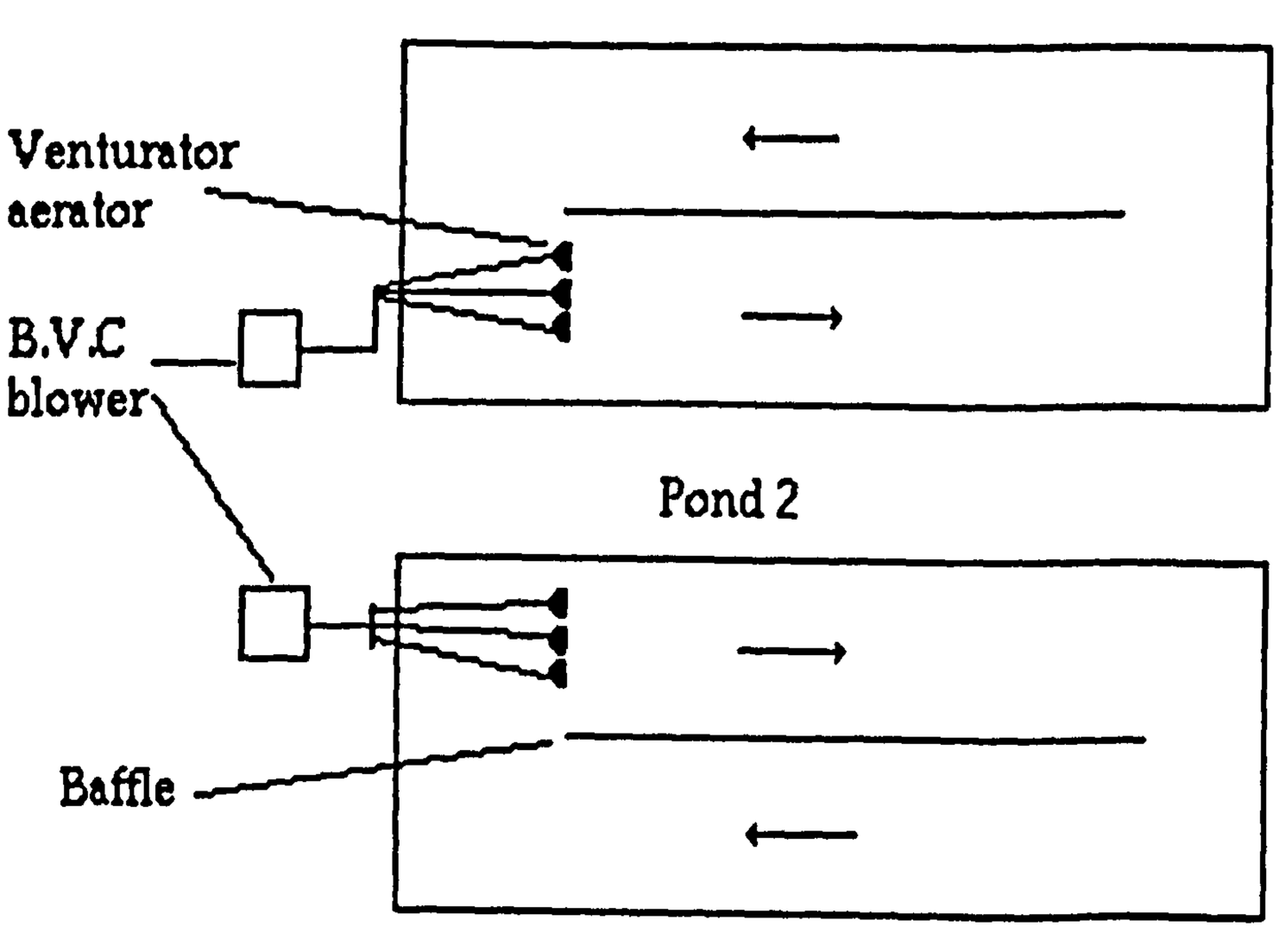


Table 14. Analysis of Kafue River Water and fish farm effluent (N.D. = Not Detected).

	Kafue River Water	Fish Farm Effluent
Calcium Hardness(mg/l)	120	N.D.
Total Hardness(mg/l)	270	220
Nitrate(mg/l)	6.5	28.5
Nitrite(mg/l)	N.D.	0.05
Ammonia(mg/l)	0.3	3.0
Phosphate(mg/l)	<0.2	<0.2
Suspended Solids(mg/l)	4.0	10.0
Dissolved Solids(mg/l)	244	314
Total Solids(mg/l)	248	324

Harvesting was carried out using a process of dissolved air flotation. A flow diagram of the process is shown in Figure 14. The algal suspension to be harvested was pumped out of the pond using a transfer pump (Mono CMD/Carter F14 Gearbox/3kw motor). This allowed the rate of pumping to be varied. As the plant was originally supplied there was no provision for the addition of a flocculant but this was found to be necessary. It was added using a dose metering pump (PDP R410/0.09 kw motor) at the outlet side of the transfer pump. Just before the flocculated algal suspension entered the flotation cell, white water was added. This was produced by a white water plant consisting of a high pressure pump and a pressure vessel running through a system which caused air to be sucked in through a venturi and enter solution in the pressure vessel. Water from the white water system was added in small quantities to the flocculated algal suspension. The reduction in pressure between the white water plant and the flotation cell caused the formation of tiny bubbles. The flocculated algal cells attached to these bubbles and floated to the surface in the flotation cell. The flotation cell had a capacity of 5.5m^3, which, at flow through rates of algal solution of 6 - 10 m^3/hr, gave a residence time in the cell of approximately 30 minutes to 1 hour. The resultant thick scum was removed periodically by a rubber bladed scraper and passed onto a vacuum assisted dewatering tray covered with a filter paper. This dried the algal sludge from approximately 1% solids to 10% solids. Further reduction in the moisture content was achieved by sun drying.

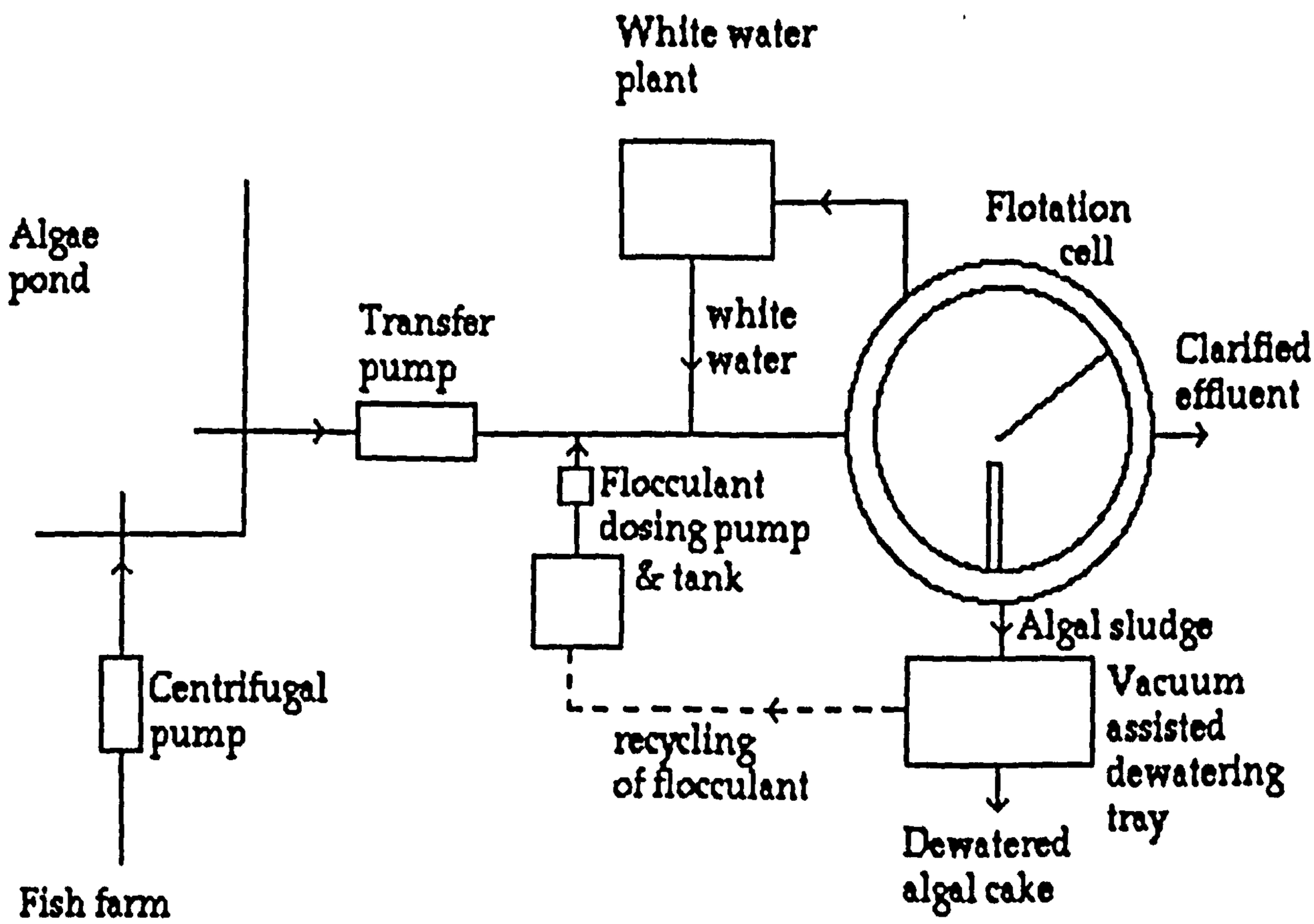
The density of algal solutions was measured by three different methods.

(a) Direct microscopic counting using an Olympus BH-2 microscope and a Gallenkamp haemocytometer.

(b) Recording absorbance of light by the solution using a Corning 254 colorimeter set at 650nm (Edwards and Sinchumpasak, 1981).

(c) Direct weighing of the dry weight by drying a sample at 105^0C.

Figure 14. Flow diagram of algal harvesting process.



pH was measured using a Jenway pH/Temperature meter 6061 or a Phillips PR 9400 pH meter. Temperatures were measured by thermometer three times daily. Nutrient levels in the cultures were estimated using a Lovibond comparometer test kit. Light levels were estimated from meteorological data collected on the sugar estate.

Efficiency of harvesting was measured by comparing the absorbance or cell density of the algal suspensions before and after harvesting. This was then expressed as %age clarification.

6.3. Cultivation.

No attempt was made to inoculate the algae cultures as the incoming water from the fish farm contained wild algae species which would have been a continual source of contamination. Table 15 is a list of the most commonly occurring genera over the course of the project. Generally once a particular culture was established there would be only one dominant algal genus.

Table 15. Checklist of algal Genera observed during the project (Those in bold type were predominant genera in cultures at some time).

Actinastrum spp.

Ankistrodesmus spp.

***Chlorella* spp.**

***Cosmarium* spp.**

***Golenkiniopsis* spp.**

***Micractinium* spp.**

***Pediastrum* spp.**

Scenedesmus spp.

Staurastrum spp.

Figures 15 and 16 show the estimated average standing crops, pH levels and fertilisation rates in ponds 1 and 2. Figure 17 shows the total quantity of algae harvested each month, the estimated incidence of light energy and the average water temperature in the ponds over the course of the project.

As can be seen from these figures, standing crops and total yields showed no relationship with water temperatures or with levels of sunlight irradiation. A closer correlation seemed to be with levels of fertilisation. Maximum standing crops and harvested yields of algae were in March 1984. It was also during this period that fertilisation rates were at their highest. Fertilisation was however very inefficient. Over a 64 day period with pond 1 operated on a closed system (effluent from the harvesting plant was returned to pond 1), fertilisation with 208 kg of urea and 20.8 kg of triple super phosphate produced only 50.4 kg of dry harvested algae. It was clear that growth of the cultures was not limited by availability of nitrogen or phosphorous as they were present at very high levels at the end of this period (ammonia 200mg/l, phosphate 80mg/l). It was also noted that increasing levels of fertilisation resulted in elevated pH levels.

The evidence suggested that the limiting nutrient in the algae cultures was carbon dioxide. This was confirmed by the observation that there was deposition of calcium carbonate on aerators and on the pond linings near the water surface. The effects of carbon dioxide supply on an algal culture are well established (Goldman, Azov, Riley and Dennett, 1982). Carbon dioxide supply is a critical factor in all but the highest "BOD" wastewater treatment algal systems (Soeder, 1980; De Pauw *et al* 1980) and those with plentiful supplies of carbon such as *Spirulina* culture in alkaline ponds (Benemann, Weissman & Oswald, 1979).

Figure 15. Estimated average standing crop, pH levels and fertilisation rates for pond 1

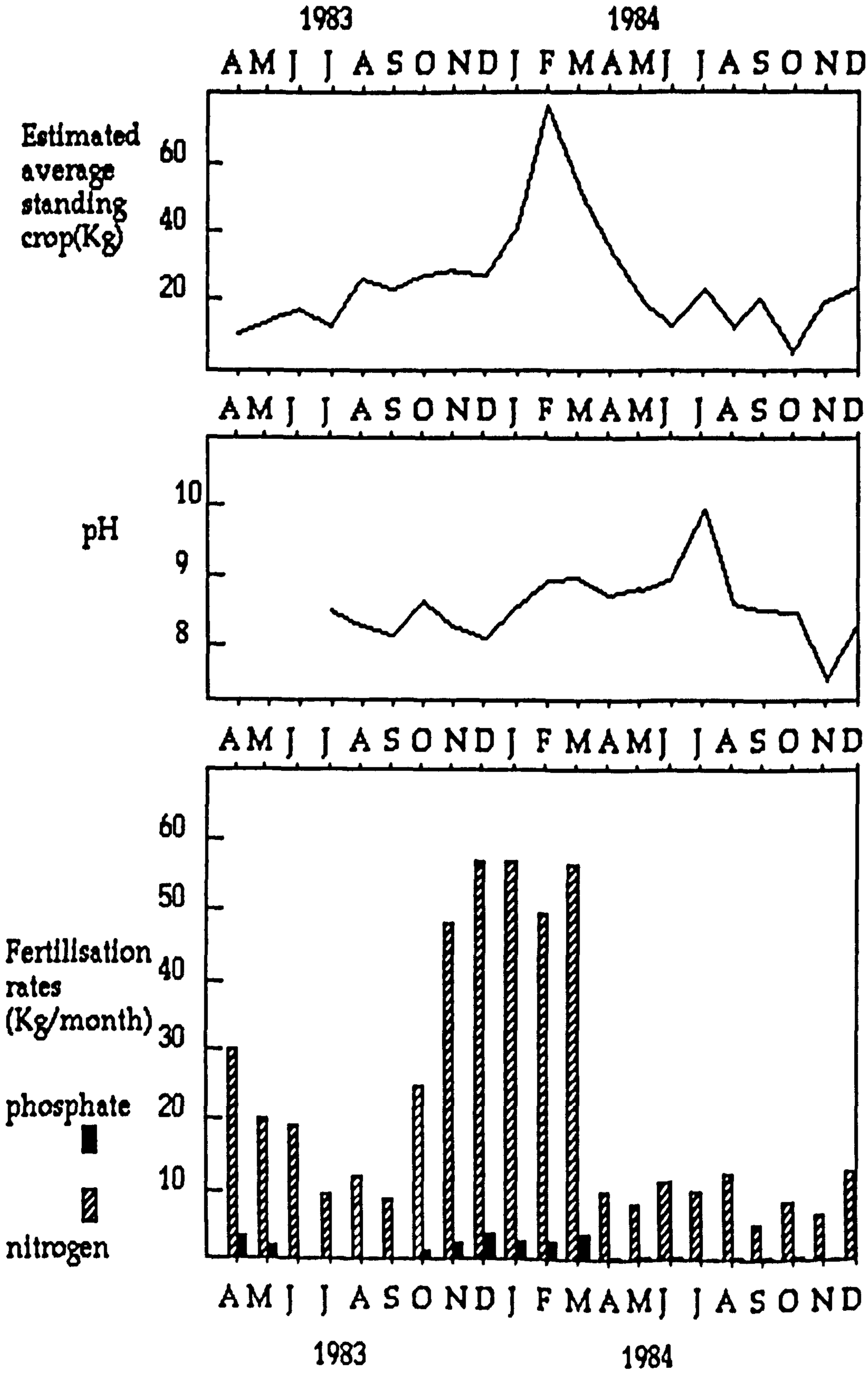


Figure 16. Estimated average standing crop, pH levels and fertilisation rates for pond 2.

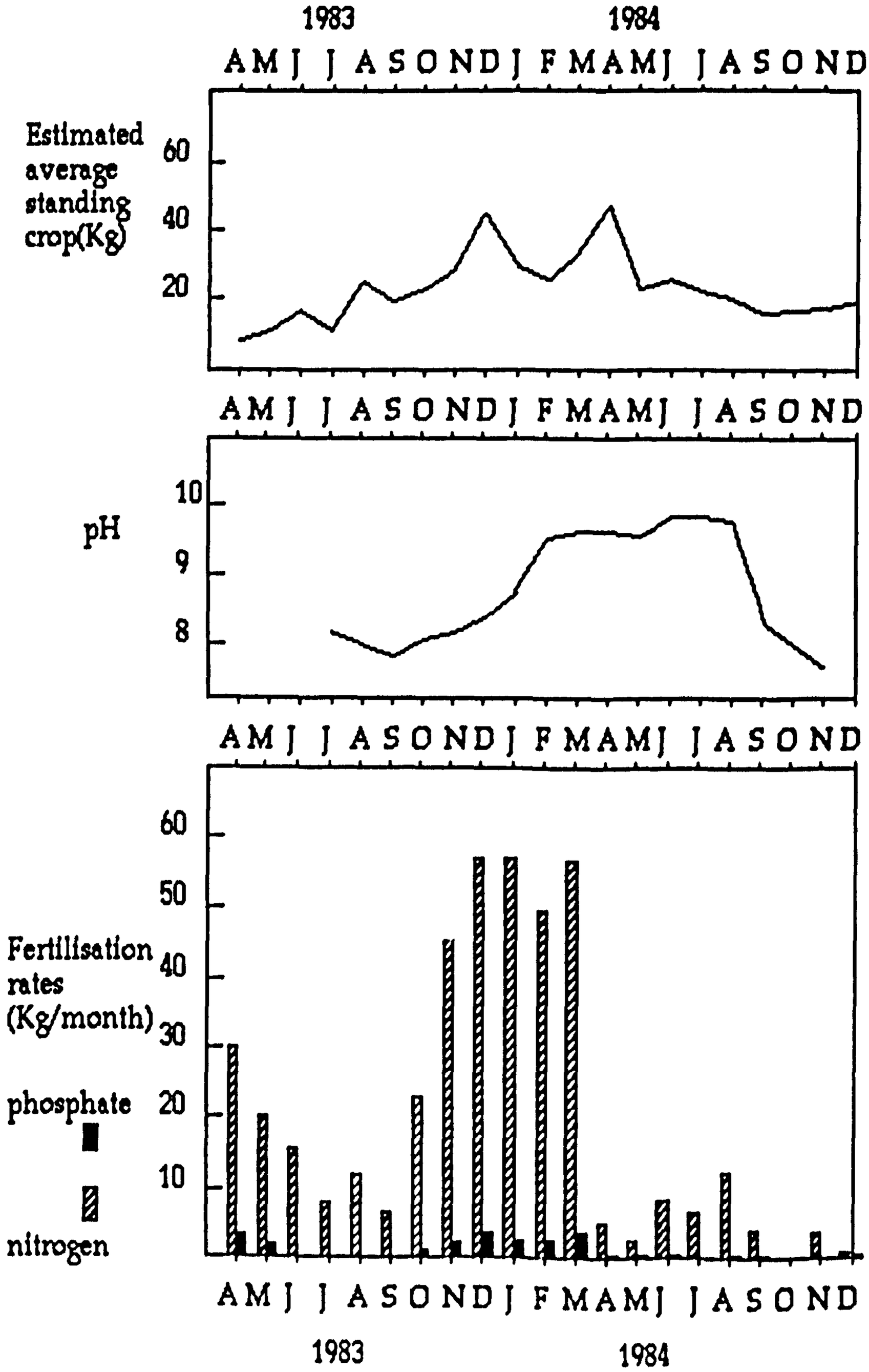
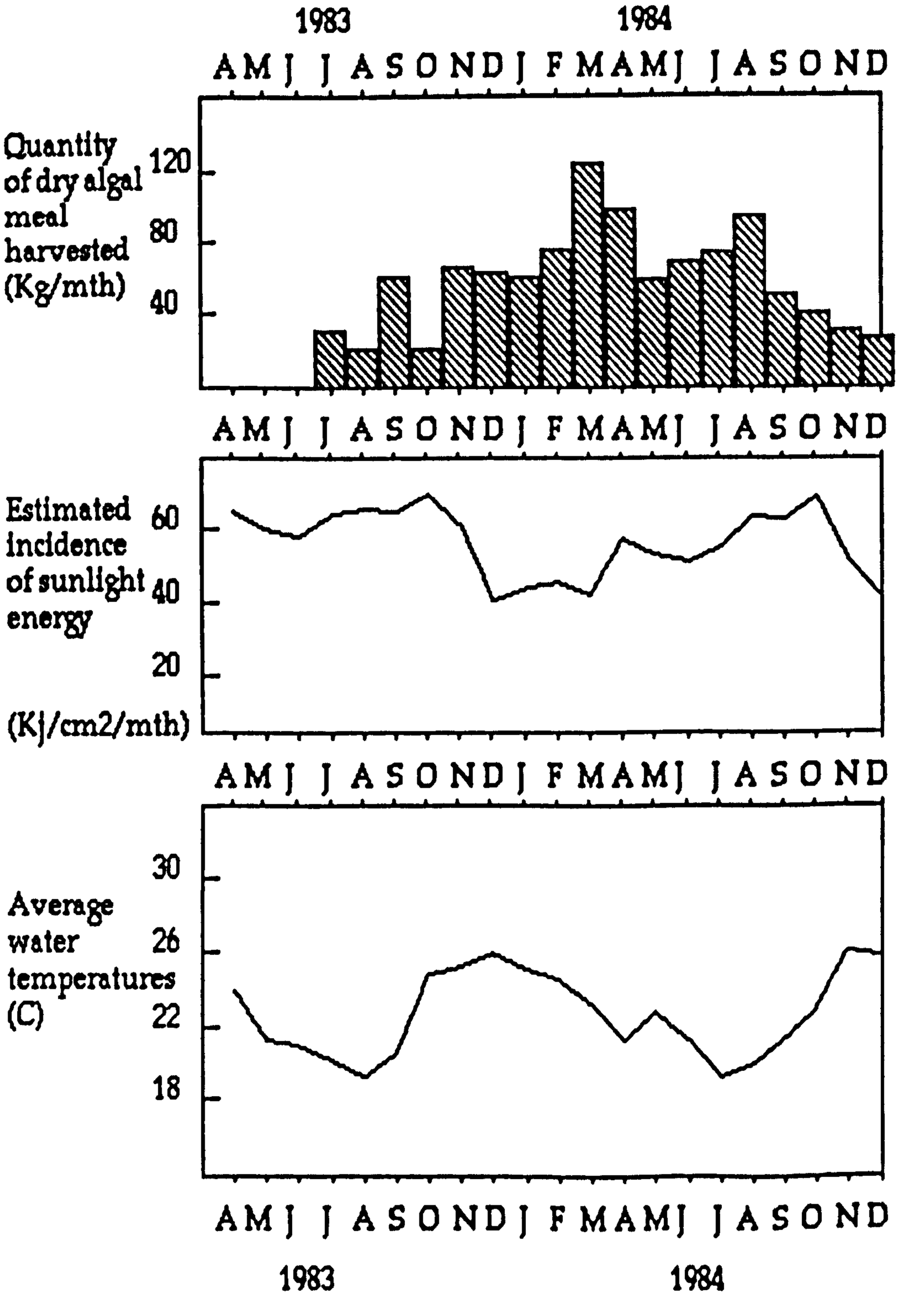


Figure 17. Algal yields, estimated incidence of sunlight energy and average water temperatures.



A shortfall in the supply of carbon dioxide results in the following:

(a) When carbon dioxide is used up, carbon is supplied by bicarbonate causing the reaction

$$HCO_3^- \rightarrow CO_2 + OH^-$$

thus raising the pH by the release of hydroxyl ions.

(b) At pH levels above 10 any free carbon dioxide which enters solution is converted to the carbonate ion (CO_3^{--}) which forms insoluble precipitates such as calcium carbonate.

(c) At high pH levels ammonium ions are converted into ammonia molecules which may then be lost to the atmosphere as ammonia gas.

It had been hoped that sufficient carbon dioxide would have been present in the water from the fish farm supplemented by aeration of the ponds but clearly this was not the case. The partial pressure of carbon dioxide in air is low (less than 0.04%) thus aeration is an inefficient means of transferring carbon dioxide into the cultures (Soeder, 1980).

Small scale experiments indicated that the pH of the algae cultures could be controlled using carbon dioxide supplied from compressed gas bottles, but we were unable to demonstrate increased productivity in a production pond as this would have required substantial changes to the culture system. A proposal was put forward to the Overseas Development Administration to supply carbon dioxide by the fermentation of of yeasts on molasses. There was an excess of molasses on the sugar estate due to distribution problems. If the fermentation took place in sealed vessels through which

air was sparged, the air could be piped off for distribution to the algae ponds as it would have been enriched with carbon dioxide in the process. The scheme would have increased productivity of the algae ponds and grown yeast as another ingredient for the tilapia feeds. Unfortunately this proposal was not supported by O.D.A. and so it was never implemented.

Two different circulation systems were set up as shown in Figure 12. There was no evidence to suggest that there was any benefit in using the more complicated and expensive system employed in pond 1. Porous tubing aerators clogged up rapidly with depositions of Calcium Carbonate. In January 1984 both circulation systems were changed to a simplified version of that used in pond 2, with no adverse effects on productivity.

Seepage of water through the plastic liners was a continual problem. The ponds were dug in an area with a high water table. When the liners were first installed, water accumulated underneath them which tore apart the taped seams. The seams were repaired by throwing concrete along them, but seepage still occurred. This made it difficult to operate the cultures in a controlled manner.

Average culture depths were reduced from 75cm to 50 cm in January 1984 which may have contributed to increased growth rates shown in the following months. It is difficult to draw conclusions given the major problem of carbon dioxide starvation of the cultures.

6.4. Harvesting.

Initially harvesting was attempted without the use of flocculants. Although some algae were floated off using dissolved air floatation alone, this was not very efficient. Table 16 gives some examples of the efficiency of harvesting using different treatments. Alum was the most readily available flocculant. Dosage with 50 - 120 mg/l effected good flocculation which allowed almost total harvesting of the algal cells in the flotation cell. Flotation was most effective at throughput rates of 3 - 6m^3/hour.

Table 16. Typical examples of data recorded from the harvesting apparatus over extended periods.

Algal Genus	% Absorbance of culture	Flocculant	Flocculant dosage(ppm)	% age Clarification
Micractinium	19.0	Alum	120	100
Scenedesmus	6.3	Alum	111	92
Chlorella	10.0	Alum	89	98
Pediastrum	9.5	Alum	85	100
Golenkiniopsis	11.8	Alum	94	96
Scenedesmus	5.5	None	-	35.5

The aluminium content of the harvested sludge was high (5% of dry weight). It was found that treatment of the harvested algal sludge with sulphuric acid according to the method of Bratby (1980) allowed some of the aluminium sulphate to be recycled. This was carried out by thouroughly mixing sulphuric acid with the coagulated sludge on the

vacuum filter tray, to reduce the pH to 2. The vacuum pump was then switched on and the filtrate, containing the aluminium sulphate was returned to the flocculant mixing tank. This also reduced the aluminium content of the sludge (to 2% of dry weight), making it easier to dry.

6.5. Algal meal quality and use.

Table 9 includes the average composition of algae meals which were analysed over the course of the project. Despite the meals being made from single cell type algae, they contained relatively low levels of protein (average = 24.4%). They also contained high levels of silt, indicated by the high ash levels recorded in proximate analysis. The silt probably originated from the river water which was used as the main substrate for growth of the cultures. Alum is often used as a flocculant to remove silt from water (Bratby, 1980), which would have allowed it to be harvested along with the algal cells in the flotation cell. This problem has not been referred to by other workers probably because other studies have not been using silty water as their substrate.

Two approaches could have been used to alleviate this problem.

(a) Pretreat all the water entering the algae ponds to remove silt, this would have doubled processing costs.

(b) Increase the concentration of algae cells in the cultures so that the diluting effect of the silt on the harvested product was reduced. This approach was obviously related to the problems outlined in the section on cultivation.

Feed trials were carried out comparing algae meals to other feed ingredients. These are described in more detail in Chapter 7.

Table 17 shows production figures and the estimated costs of production per kilogramme of dry algal meal. These figures include running costs, labour and a figure to account for depreciation of the plant. The depreciation figure was substantial, up to 60% of total costs depending on which culture system was in use. Flocculant became a major cost towards the end of the project as Alum increased in price from ZK40 to ZK198 per 50kg bag in late 1984. If these production costs are compared with those of other feed ingredients of similar composition (see Table 10), it can be seen that algal meal was not economical at this price and quality.

There were two reasons why use of algal meal was not economical:

(a) The quantity of algae produced was not sufficient to offset the high capital and running costs incurred. Yields of up to 53g/m^2/day have been reported from a research team producing *Scenedesmus obliquus* in Peru (Soeder, 1980). Benemann *et al*, (1979) reported yields of over 20g/m^2/day for small systems. In contrast the highest average monthly yield at Nakambala was 5.1g/m^2/day. This was probably mainly due to carbon dioxide starvation of the cultures.

(b) Low quality of the algal meals. Contamination with silt meant that the value of the algal meals was low compared to the other ingredients which were available for inclusion in the fish feeds.

A completely different approach was adopted by the AIT team in Bangkok (Edwards and Sinchumpasak, 1981; Edwards *et al* 1981(a); Edwards *et al* 1981(b)), who used tilapias growing in an algal pond to harvest the microalgae. They reported mean algal yields of 15.7g/m^2/day and fish yields approaching the equivalent of 20 tonnes/ha/year. Although this approach seems attractive, growing fish in sewage loaded ponds raises questions of public health and particularly in countries such as Zambia, public acceptability.

Table 17. Summary of production figures and estimated costs.

		Production (g/m2/day)	Estimated cost of production(ZK/Kg)
1983	July	1.28	-
	August	1.05	-
	September	2.51	15.75
	October	0.85	-
	November	2.68	-
	December	2.58	-
1984	January	2.44	-
	February	3.57	-
	March	5.14	5.80
	April	4.50	5.52
	May	2.48	9.84
	June	3.10	8.42
	July	2.90	8.26
	August	3.97	6.17
	September	2.17	11.08
	October	3.52	12.87
	November	1.48	15.39
	December	1.81	26.13

6.6. Conclusions.

The following recommendations and observations can be made on the experience gained from this project.

(a) An algal plant should be situated to take advantage of as many free nutrients as possible. Carbon and nitrogen should be freely available in an area with high levels of sunlight. Distilleries or chemical plants in the tropics may be suitable locations.

(b) The capital cost of the production facility should be kept to a minimum by using earth ponds. Mixing could be carried out by small submersible pumps.

(c) The harvesting plant is the main capital cost and should be appropriately sized so that it is operating continuously. Further research is required on appropriate dewatering and drying techniques for the algal meal.

(d) Although this project demonstrated that algal culture was not viable in this particular format at Nakambala, this does not mean that it should be neglected as a possible solution to the world shortage of high quality feed ingredients. This applies particularly to countries such as Zambia which can no longer afford the foreign exchange necessary to import such materials and so must depend on local supplies if they are to manufacture any stockfeeds for intensive animal production. Tropical countries have an advantage over temperate countries because sunlight irridiation levels are highest near the equator. With the right location and the appropriate research effort, algae culture may well have a role to play in these countries.

CHAPTER 7. RESEARCH AND FEED TRIALS.

Generally research work was carried out separately to the main production activities on the farm. The main aim of research was to determine, through experimentation, solutions to particular problems which arose in the operation of the main farm. Most of the research trials concentrated on evaluation of the effect of changes in feed formulations on fish performance however other subjects such as comparison of fish species were also addressed.

The trials are presented in chronological order however they can be grouped into three main categories:

A Trials 1 - 8 carried out in rectangular tanks which were not self cleaning. These concerned a number of subjects however results were often confused by the poor growth performance of fish in the tanks, probably due to tank design.

B Trials 9 - 14 carried out in self cleaning tanks (basin tanks and outside tanks) on vitamin supply in feeds. All these trials were designed to determine whether or not vitamin supplementation of the feeds was necessary. This was seen as being very important as a vitamin supplement was the only feed raw material which had to be imported into Zambia. As time went on importation became increasingly difficult leading to the conclusion that if it was essential for a vitamin supplement to be included in feeds, then manufacture of such feeds on a regular basis would have been impossible.

C Trials 15 - 17 carried out in self cleaning tanks on other subjects.

A. Trials carried out in rectangular non self cleaning tanks.

7.1. Feed trial 1. Protein and vitamin sources.

Introduction

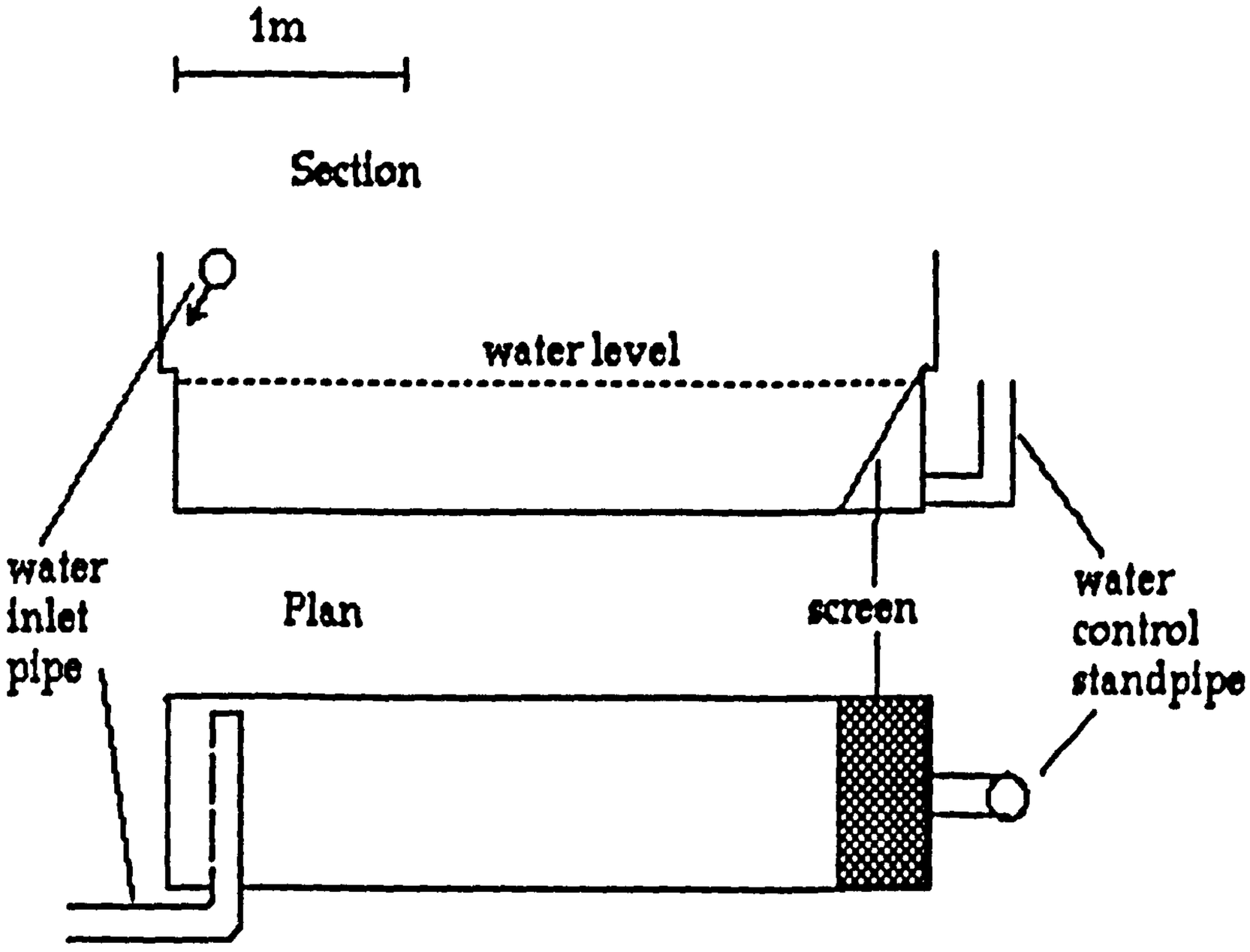
Feed trial 1 was designed to investigate the effect of using different protein and vitamin sources in the feeds. The protein sources were screw pressed soya bean oilcake, kapenta, fish silage and microalgae. The vitamin sources were yeast and a vitamin and mineral premix (see below for details).

Materials and methods.

This feed trial was carried out in 5 test tanks, situated at the rearing unit (see figure 6). Each tank measured 3m x 0.7m with a water depth of 0.4m (see figure 18). Kafue river water (see table 14) was supplied by a sparge pipe situated at one end of the tank, at a flow rate of $1m^3$/hr. Water was discharged at the other end through a flat inclined screen to an external swinging arm standpipe which also controlled the water level in the tank.

Each tank was stocked with 100 *Oreochromis macrochir* of approximately 10g average weight. The fish were all derived from the same production tank. The fish were allowed to acclimatise for a period of 32 days, during which they were fed normal production feeds (see table 11). Five feeds were formulated to supply 30% crude protein as shown in Table 18. Proximate analysis had not been carried out on the raw

Figure 18. The test tanks.



materials, so the nutrient levels used in formulation were derived from Gohl (1981). The main protein sources used were soya bean oilcake (screw pressed as in section 5.2), kapenta (from a batch which had been rejected by the kitchens because it was too dusty), fish silage (see section 5.4) and algal meal (produced from the algae project - see chapter 6). Two vitamin sources were used, a vitamin and mineral premix (Multivit P, Assia Maabarot Ltd, Tel Aviv Israel - contents in table 18) and yeast (see section 4.7).

Feed 1 was designed as the control, containing equal amounts of protein contributed by kapenta and fish silage, and also containing the vitamin/mineral premix. In feed 2, all the animal protein was supplied by kapenta and the vitamin/ mineral mix was also used. Feeds 3 and 4 contained the same protein sources as the control, however no source of vitamins was used in feed 3 and yeast was used in feed 4. In feed 5, kapenta was replaced by algae meal as one of the main protein sources.

The feeds were made up by mixing the milled ingredients thoroughly with a shovel, and passing them through the Lister pelleter fitted with a 2.5mm die(see section 5.6). Each feed was allocated to one tank of fish. At the start of the trial on 27/4/83, all the fish were counted and bulk weighed (Salter top pan scale), following anaesthetisation with benzocaine (1:15000). A ration of 3.5% of body weight/day was calculated for each tank, and fed in 3 - 5 hand feeds/day. Each tank was reweighed and counted at 14 days, 28 days and at the termination of the trial after 38 days. Water temperatures fell during the trial from 25°C at the end of April to 20°C at the start of June. Specific growth rates and food conversion ratios were calculated as shown in table 18. Statistical analysis of the data was not possible because the treatments were not replicated.

Table 18. Feed formulations in feed trial 1 (Expressed as %age of total feed as fed).

Feed number	1	2	3	4	5
Maize	55.4	55.4	55.6	54.3	55.4
Soyabeanoilcake	33.2	33.2	33.3	32.6	33.2
Kapenta	5.5	11.0	5.6	5.4	-
Fish silage	5.5	-	5.6	5.4	5.5
Algae	-	-	-	-	5.5
Vit/Min*	0.22	0.22	-	-	0.22
Yeast	- -	-	2.2	-	

* Multivit P(Assia Maabarot Ltd, Tel Aviv, Israel) - contents/2kg pack. - vitamin A, 10000000 I.U; vitamin D 1000000 I.U; vitamin E, 2000 I.U; vitamin K, 2000mg; vitamin B2, 5000mg; vitamin B12, 10mg; nicotinic acid, 25000mg; pantothenic acid 11000mg; choline chloride, 300000mg; antioxidant, 125000mg; procaine penicillin, 10000mg; manganese, 80000mg; zinc, 50000mg; iron, 25000mg; copper, 2000mg; cobalt, 1200mg; iodine, 200mg.

Results

The results in table 19 show that generally growth was poor for this size of fish (specific growth rates from 0.47 - 0.9) and particularly in fish fed feed 1, the control feed (S.G.R. = 0.47). Food conversion ratios were also high ranging from 14.06 to 4.02. Best performance was shown in tanks fed feeds without the vitamin premix (tanks 3 and 4).

Table 19. Results from feed trial 1.

Feed number	1	2	3	4	5
Initial Number	96	94	99	94	98
Init. Avge Weight(g)	14.75	14.13	13.13	15.40	16.29
Final Number	89	88	94	92	87
Final Avge. Wt.(g)	17.64	18.30	18.32	21.70	21.22
S.G.R.	0.47	0.68	0.88	0.9	0.7
F.C.R.	14.06	7.14	4.68	4.02	9.73

Specific growth rate(S.G.R.) = $(\log_e w_2 - \log_e w_1)/t \times 100$

w_1 and w_2 are the initial and final average weights(grammes), respectively.

t = length of test period in days.

Food conversion ratio(F.C.R.) = Weight of food fed/weight gain of fish.

Discussion

Very little can be deduced from this trial, because of the relatively low growth rates, high food conversion ratios and the fact that no statistical analysis can be carried out because the treatments were not replicated. It was clear, however, that fish performance was not enhanced by the presence of the vitamin premix in the feeds as the fish fed the three feeds with the premix, grew worse than the two tanks of fish fed feeds without the premix. The premix was intended for broiler chickens and had a vitamin balance quite different from the vitamin requirements proposed by the University of Stirling (see table 2). The premix also contained an antibiotic (procaine penicillin - 11mg/kg of feed). The possible effects of this are unknown.

The growth rates were lower than has been suggested for *O. macrochir* in ponds. Maar *et al* (1966) indicated that *O. macrochir* should be able to grow at the equivalent of a specific growth rate of 0.92%/day between 10 and 90g weight in Zambia.

7.2. Feed Trial 2. Comparison of fish species.

Introduction

This trial compared the growth of the five different species which were available for culture at Nakambala including two indigenous species, *Oreochromis macrochir* and *Oreochromis andersonii*, and three exotic species *Oreochromis niloticus*, *Oreochromis aureus*, and Mirror Carp (*Cyprinus carpio*). The main objective was to evaluate which of the species held most potential for culture at Nakambala, so that efforts in the hatchery could be directed towards that species.

Materials and methods

This trial was carried out in five test tanks (described in feed trial 1) supplied with Kafue river water (temperature 24 - 25°C during the trial). Each of five test tanks was stocked with approximately 50 fish of one of the species. The *O. macrochir* and *O. andersonii* came from production tanks in the rearing unit. The original stock for both species came from irrigation dams on the sugar estate. *O. aureus* and *O. niloticus* were the first generation progeny from fish imported from the University of Stirling. The mirror carp were part of a batch purchased from the F.A.O./ Fisheries Department research station at Chilanga, Zambia.

The fish were bulk weighed (as in feed trial 1) and counted at the start of the trial and subsequently at 14 days, 28 days and at the termination of the trial after 40 days.The fish were fed standard production feeds (see table 11) at 4% of body weight/day in 3 - 5 hand feeds/day.

Results

The results are shown in Table 20. Carp perfomed best with a specific growth rate of 1.29 and a food conversion ratio of 3.34. Of the tilapias, *O. andersonii* grew best, although an S.G.R. of 0.74 and an F.C.R. of 5.1 cannot be considered as good growth. The other tilapias showed very poor growth (S.G.R.'s, 0.49 - 0.51) and had high food conversion ratios. Some of the tilapias showed clear signs of breeding activity, particulary *O. macrochir, O. aureus*and *O. niloticus* Male fish had established "nests" in the tanks, which were being actively defended. At weighing, females from these three tanks were found to be carrying eggs.

Table 20. Results from Feed Trial 2.

Species	*O. macrochir*	*O. niloticus*	*O. aureus*	*O. andersonii*	*C. carpio*
Initial Number	51	50	50	50	51
Init. Avge Weight(g)	31.0	34.8	18.3	25.7	33.7
Final Number	50	49	50	50	46
Final Avge. Wt.(g)	37.9	42.4	22.4	34.6	57.9
S.G.R.*	0.50	0.49	0.51	0.74	1.29
F.C.R.*	8.0	8.6	8.5	5.1	3.3

* calculated as in feed trial 1.

Discussion

Growth of the different species was clearly dominated by reproductive behaviour. Precocious maturity of tilapias has long been recognised as a problem in extensive culture (Balarin and Hatton, 1979) and in intensive tanks, even small differences in tank configuration can have a profound effect on fish behaviour (Dickson, 1981). The main priority in reducing precocious maturity in tilapias seems to be to provide a featureless environment for the fish, such as in round or D - ended tanks where water flow is more or less even throughout the tank. As soon as male tilapias are able to establish nests and territories, females will mature with a consequent reduction in growth rates of the fish. Highest growth in this trial was with those fish which did not engage in breeding activity. Carp do not breed at this size or in this type of environment. *O. andersonii* tend to mature later than other tilapias (Maar *et al* 1966). This may be why they appeared to grow better than the other tilapias in this trial.

The trial was disappointing because the results were obviously specific to this particular tank system and could not be applied to the main production tanks.

7.3. Feed Trial 3. Protein levels and use of a vitamin premix.

Introduction

By the end of 1983, it was clear that there were growth problems in the main production tanks. The farm was stocked mainly with *O. macrochir* which grew reasonably well up to 70 - 80g after which growth slowed dramatically (see section 3.3). Dr Kim Jauncey of the Institute of Aquaculture, University of Stirling, visited the farm for two weeks in November 1983. The aim of the visit was to develop feed formulations for the farm (Jauncey, 1984). One suggestion made by Dr Jauncey was that the feeds were probably deficient in vitamins. Although there were no normal supplies of vitamin premixes in Zambia at the time, a bag of a vitamin premix intended for pigs was obtained (Nutra mix AIF - Hoescht Ltd.). The vitamin premix was used in feed trial 3 to try to determine whether the growth problems were related to vitamin supply.

Materials and methods

The trial was carried out in six test tanks (as described in feed trial 1). During this trial the tanks were supplied with borehole water(24 - 25°C). Each tank was stocked with 50 *O. macrochir* of approximately 28g average weight from a single production tank.

Six feeds were made up according to the formulations shown in table 21, by the same methods as used in feed trial 1 except that a 4mm pelleting die was used. Feed 1 used a standard fingerling formulation, feed 2 used an "improved" formulation containing higher levels of algae, blood, cottonseed oilcake and yeast and reduced maize and soya bean oilcake. Feed 3 was formulated to contain higher levels of protein than feeds 1 or 2. Feeds 4, 5 and 6 had the same formulations as feeds 1, 2 and 3 respectively, except that they contained 1% of the Hoescht vitamin premix (see table 21).

The fish were acclimatised for four days during which they were fed production fingerling food (see table 11). At the start of the trial, the fish were bulk weighed (method as feed trial 1) and counted. Each feed was allocated to one tank and fed at 3% of body weight/day in 3 - 5 hand feeds/day. The fish were reweighed and counted after 14 days and at the termination of the trial at 24 days.

Table 21. Feed formulations from Feed Trial 3. (%age of total feed as fed)

Feed number	1	2	3	4	5	6
Formulations(%)						
Algae	27	5	10	27	5	10
Blood(Dried)	5	6	7	5	6	7
H.F.M.	5	5	5	5	5	5
Maize	20	9	5	19	8	4
Fish Silage	5	5	15	5	5	15
Wheatings	30	30	18	30	30	18
Soya	20	15	20	20	15	20
Cottonseed	10	20	10	10	20	10
Yeast	23	5	10	23	5	10
Vit.Mix*	-	-	-	1	1	1

* Nutramix AIF(Hoechst) contained(/kg): Vitamin A, 3333000 I.U; Vitamin D3, 666700 I.U. ; Vitamin E, 3335 I.U; Vitamin K, 1670mg; Vitamin B1, 335mg; Vitamin B2, 1330mg; Vitamin B6, 165mg; Vitamin B12, 3.5 mg; Nicotinic acid, 8330mg; Pantothenic acid, 3330mg; Choline chloride, 100000mg; Folic acid, 335mg; Biotin, 10mg.

Results and discussion

The results shown in table 22 show very poor growth in all the tanks. The average weight of the fish in all but two of the tanks actually fell over the test period. This trial demonstrated that the growth problem encountered with *O. macrochir* was not relieved by feeding feeds with elevated protein levels or with this vitamin premix.

Table 22. Results from feed trial 3.

Feed number	1	2	3	4	5	6
Initial Number	50	50	50	50	50	50
Init.Avge.Wt.(g)	28.9	29.4	27.9	27.7	30.9	29.8
Final Number	48	45	46	48	50	48
Final Avge. Wt.(g)	27.8	28.4	27.1	27.6	34.7	31.4
S.G.R.	-ve	-ve	-ve	-ve	0.48	0.22

7.4. Feed Trial 4. Use of a range of vitamin premixes.

Introduction

Feedtrial 3 had been carried out with the only vitamin premix available at the time. Due to the seriousness of the growth problem in the production fish, supplies of other vitamin mixes were secured. These were Multivit P (as used in feed trial 1) and vitamin and mineral premixes used in the manufacture of a trout feed in South Africa (Epoll Ltd.) Feed trial 4 was to dtermine whether growth could be improved by the use of any of these supplements.

Materials and methods.

Because of the urgency of the situation, the same fish and tanks as had been used for feed trial 3 were used for feed trial 4. Six feeds were made up, according to the formulations shown in table 23, by mixing the milled ingredients and pelleting using the Lister pelleter with a 4mm die (see section 5.6). Each feed contained different vitamin and/or mineral supplements. Each feed was allocated to one tank and fed at 3% of body weight/ day in 3 - 5 hand feeds/ day. The fish were reweighed, counted and the rations adjusted after 14 days and at the termination of the trial after 28 days.

Table 23. Feed formulations from Feed Trial 4 (% age of feed as fed).

Feed number	1	2	3	4	5	6
Formulations(%)						
Algae	2.7	2.7	2.7	2.7	2.7	2.7
Blood(Dried)	5	5	5	5	5	5
H.F.M.	5	5	5	5	5	5
Maize	20	19	19.3	19	19.65	19.1
Fish Silage	5	5	5	5	5	5
Wheatings	30	30	30	30	30	30
Soyabean oilcake	20	20	20	20	20	20
Cottonseedoilcake	10	10	10	10	10	10
Yeast	2.3	2.3	2.3	2.3	2.3	2.3
Multivit P[1]	-	1.0	-	-	-	-
Nutramix AIF[2]	-	-	-	1.0	-	-
Epoll Vitamin mix[3]	-	-	0.7	-	0.35	0.7
Epoll Mineral mix[4]	-	-	-	-	-	0.2

Table23(Contd.)

1 - Multivit P - as in feed trial 1.

2 - Nutramix AIF - as in feed trial 3.

3 & 4 - Epoll vitamin and mineral premixes were proprietary formulations used in trout feeds produced by the Epoll Feed Company Ltd., Durban, Republic of South Africa.

Results and discussion

The results in table 24 show that once again growth was very poor. Although the average weights of fish in each tank rose (S.G.R's 0.02 - 0.34), mortalities during the trial left three of the tanks with lower total fish weights, than at the start of the trial, resulting in food conversion ratios of infinity. Clearly there was something very badly wrong with these fish, which did not respond to supplementation of the feeds with vitamins, from whatever source.

Table 24. Results of feed trial 4.

Feed number	1	2	3	4	5	6
Init. Number	48	45	46	48	50	48
Init.Avge.Wt.(g)	27.8	28.4	27.1	27.6	34.7	31.4
Final Number	43	41	40	44	50	48
Final Avge. Wt.(g)	29.5	31.2	28.4	29.4	34.9	32.9
S.G.R.*	0.21	0.34	0.17	0.29	0.02	0.17
F.C.R.*	inf.	895	inf.	inf.	146	17.6

* calculated as in feed trial 1. inf. = infinity.

7.5. Feed Trial 5. Use of Epoll vitamin and mineral premixes vs. Epoll trout feed.

Introduction

Results from feed trials 1, 3 and 4 had failed to indicate that the growth problems observed in *O. macrochir* in production tanks, could be relieved by increasing the dietary protein levels in the feeds, or by using vitamin supplements in the feeds. The few *O. aureus* and *O. andersonii* which had been stocked in the production tanks, appeared to be growing much better than the *O. macrochir* (see table 6). It was decided that feed trial 5 should use O. aureus, and that the treatments should be duplicated. The *O. aureus* were also to be sexed as all-males to circumvent the problems with precocious maturity observed in feed trial 2. The aim of the trial was to determine whether a vitamin supplement was required in the feeds. In addition to feeds manufactured at Nakambala, a bag of trout food had been imported from South Africa. This was to be used as a control, to determine whether good growth could be achieved at all in the test tanks. At the same time as feed trial 5 was being run, a production tank of *O. andersonii* in the rearing unit was fed the remainder of the trout food.

Materials and methods

Feed trial 5 was carried out in 6 test tanks (as described in feed trial 1), supplied with borehole water. Each tank was stocked with 23 *O. aureus* males, hand sexed by the method described in Maar *et al* (1966), from one of the holding tanks in the rearing unit. The fish were allowed to acclimatise for 6 days, during which they were fed production fingerling food (see table 11). Two feeds were made up according to the formulations shown in table 25, by mixing a single batch of milled ingredients thoroughly and splitting the mix into two batches, to one of which was added the

vitamin and mineral premixes. Both batches were then remixed and pelleted separately in the Lister pelleter (see section 5.6) using a 4mm die. The other feed used was a trout feed which was imported from South Africa (Epoll Ltd, Durban, R.S.A. - Trout grower - minimum 38% protein). Each feed was randomly allocated to two tanks.

At the start of the trial, the fish in each tank were bulk weighed(as in feed trial 1) and counted. Each feed was fed at a rate of 4% of body weight/day in 3 - 5 feeds/day. The fish were reweighed, counted and the rations adjusted at 14 , 28, 42 and 48 days when the trial ended.

A sample of trout food and a sample of feed 1 was sent off for proximate analysis by the University of Stirling by A.O.A.C. methods (Jauncey, personal communication). No sample was taken of feed 2 as it was assumed that it would be identical to feed 1, having come from the same feed mix.

Results

Results are shown in table 25. Best fish growth was in the two tanks fed trout food (average S.G.R. = 1.06) which was higher, though not statistically significantly higher, than the growth rates of fish fed the locally formulated feeds (S.G.R. range 0.46 - 0.86). There was no significant difference shown in growth between fish fed feeds 1 and 2, with and without the vitamin and mineral premix respectively. Food conversion ratios were poor (F.C.R. range 3.3 - 9.00).

Proximate analysis of the feeds (Table 25) showed that the crude protein content of the trout food was much higher than that of the other feeds.

Table 22. Feed formulations (expressed as %age of total feed as fed) **and results from Feed Trial 5.**

	1	2	3
Formulations(%)			
Fish silage	5	5	-
Algae	5	5	-
Blood(dried)	5	5	-
Soya oilcake	10	10	Epoll
Cottonseed oilcake	10	10	Trout
Sunflower oilcake	20	20	Feed
Maize	10	10	-
Wheatings	30	29.1	-
Dry fish	5	5	-
Epoll Vitamin mix	-	0.7	-
Epoll Mineral mix	-	0.2	-
Proximate analysis(%age dry matter)			
Crude Protein	23.5	-	35.7
Ether Extract	5.7	-	4.6
Ash	5.8	-	11.9
Results			
Initial Avge. Weight(g)	63.1	70.5	65.0
Final Avge. Weight(g)	84.8	100.7	109.2
% Mortality	2.2	2.2	0
Average S.G.R.*	0.6 ^{a}	0.71 ^{a}	1.06 ^{a}
Average F.C.R.*	7.35 ^{a}	5.5 ^{a}	3.45 ^{a}

* calculated as in feed trial 1.

Figures in the same row with the same superscript are not significantly different. $P<0.05$. (Duncan, 1955)

Discussion

This feed trial demonstrated that growth could be achieved with tilapias in the test tanks, however growth rates were disappointing, and food conversion was very poor. The production tank of *O. andersonii* in the rearing unit which was being fed trout food, was achieving much better growth, with a specific growth rate of 3.2 from 7.5g - 44g. Growth in feed trial 5 was similar to that reported by Jackson *et al* (1982) for smaller sized all male *O. mossambicus* (S.G.R. range 0.19 - 1.25, fish average initial weights range 12.4 - 52.3g).

Fish growth seemed to be slightly better for those fed the trout food, probably because of the much higher protein content. This trial did not indicate that vitamin supplementation of the locally produced feed, resulted in an improvement in fish performance.

7.6. Feed Trial 6. Feeds with two protein levels with and without a vitamin premix.

Introduction

Feed trial 5 had shown that growth was possible in the test tanks, provide that a single sex culture of a fish species other than *O. macrochir* was used. Feed trial 6 was to investigate the effect of two levels of protein in feeds made at Nakambala, with, and without vitamin supplementation, over an extended period.

Materials and methods

This trial was carried out in eight test tanks (as described in feed trial 1) supplied with borehole water. Each tank was stocked with 50, hand sexed, male, *O. aureus* of approximately 25g average weight, from the same production tank. The fish were allowed to acclimatise for two weeks during which they were fed production fingerling food (see table 11).

Four feeds were made up according to the formulations in table 26. These were prepared in two batches, one for the normal protein level feeds 1 and 2, the other for the higher protein level feeds 3 and 4. Each batch was milled, mixed, then split into two separate batches, to one of which was added the vitamin and mineral supplement (Epoll - as used in feed trials 4 and 5). The feeds were then pelleted separately in the Lister pelleter (see section 5.6) using a 4mm die.

Each feed was randomly allocated to two tanks of fish and fed at a rate of 3.5% of body weight/ day in 3 - 5 hand feeds/day. The fish in each tank were counted and weighed (as in feed trial 1) at the start of the experiment and at fortnightly intervals thereafter until the trial finished after 98 days. Proximate analysis of each feed was carried out by

the laboratory of the National Milling Company, Lusaka, using A.O.A.C. methods (Horwitz, 1980).

Table 26. Feed formulations (expressed as %age as fed) and **proximate analysis** (expressed as %age of moisture free weight) **from Feed Trial 6.**

Feed Number	1	2	3	4
Feed Formulations(%)				
Fish silage	5	5	5	5
Algae	3	3	3	3
Blood	5	5	5	5
Soya oilcake	10	10	10	10
Cottonseed oilcake	10	10	10	10
Sunflower oilcake	10	10	10	10
Wheatings	42	41	22	21
Yeast	5	5	5	5
Kapenta	10	10	30	30
Epoll Vitamin mix*	-	0.7	-	0.7
Epoll Mineral mix*	-	0.3	-	0.3
Proximate Analysis(%)				
Moisture	9.1	10.3	9.1	7.6
Crude Protein	38.6	38.0	47.2	46.9
Ether Extract	9.7	9.0	8.9	8.8
Crude Fibre	3.8	2.4	3.2	3.9
Ash	8.1	7.7	9.9	10.2

* as used in feed trials 4 and 5.

Results and discussion

The results, in Table 27, show that growth of the fish was reasonably good (S.G.R. range 1.28 - 1.52) with much better feed conversion than had been achieved in these tanks before (F.C.R. range 2.13 - 2.61). Differences between growth rates and food conversion ratios of fish fed different feeds were not statistically significant. Proximate analysis of the feeds showed that the crude protein level in both sets of feeds was very high, 38% and 47%. This is well in excess of the protein levels recommended for tilapias of this size (see section 1.2), and probably contributed towards the satisfactory growth shown by the fish. There was no apparent difference in growth between fish fed feeds containing the vitamin and mineral supplements and those without.

Table 27. Results of feed trial 6

Feed number	1	2	3	4
Initial Avge. Wt.(g)	27.2	26.1	27	25.4
Final Avge. Wt.(g)	97.6	100.5	98.6	111.9
% Mortality	2.5	4.0	1.0	1.2
Average S.G.R.*	1.31	1.38	1.32	1.51
Average F.C.R.*	2.56	2.41	2.46	2.17

* calculated as in feed trial 1

7.7. Feed Trial 7. Replacement of animal protein with plant protein.

Introduction

Feed trials 5 and 6 had demonstrated that tilapias could be grown in the test tanks, if only males were used, and the protein level in the feed was high enough. Protein and particularly animal protein, was however, the most expensive and most difficult major nutrient to supply in the feeds. This trial was designed to investigate to what extent animal protein could be replaced by plant protein supplied by microalgae, filamentous algae and leucaena.

Materials and methods

All of the ten test tanks were used (as described in feed trial 1) supplied with borehole water (water temperature 24 - 25°C). Each tank was stocked with 100 unsexed *O. aureus* of approximately 15g average weight, from one production tank. The fish were allowed to acclimatise for two weeks before the start of the trial, during which they were fed production fingerling food (see Table 11).

Five feeds were made up according to the formulations shown in Table 28. These were all formulated to supply 30% crude protein. feed 1 was the control, with kapenta and soya bean oilcake as the main protein sources. In feeds 2 and 3, 50% and 75% respectively of the kapenta was replaced by microalgal meal (see Chapter 6). In feeds 4 and 5, 50% of the kapenta was replaced by filamentous algae and leucaena, respectively. Filamentous algae (*Spirogyra spp*) was harvested from an outdoor channel carrying effluent from the farm. The algae was sun dried before use in the feed.

Leucaena was collected from a plot of land belonging to Ceres Farms Ltd, Mazabuka (see section 4.7). No vitamin supplements were used in the feeds. The ingredients for each feed were weighed out separately, milled and pelleted (Lister pelleter - 4mm die - see section 5.6).

Each feed was allocated to two tanks and fed at 3.5% of body weight/ day. The fish in each tank were bulk weighed (as in feed trial 1) counted and rations set at the start of the trial, at fortnightly intervals, and at the end of the trial after 99 days. A sample of each feed was taken for proximate analysis by the laboratory of the National Milling Company Ltd., Lusaka (A.O.A.C. methods[Horwitz, 1980]).

Results

The results in Table 28, show that fish growth rates were reasonably good (S.G.R. range 1.27 - 1.60) as were the food conversion ratios (range 2.25 - 2.99). Although growth appeared to be slightly higher in fish fed feeds 1 and 5, the differences were not enough to be statistically significant. Differences in food conversion were also not statistically significant. Proximate analysis of the feeds indicated quite large differences in the crude protein levels, despite formulation of each to provide 30% crude protein. This was probably due to differences between the crude protein levels of the ingredients used and the levels recorded in previous samples. Relatively high mortalities were recorded in fish fed feed 1, however the surviving fish showed no obvious signs of distress. The raw material costs for each feed was estimated to allow economic evaluation of the trial. Feeds containing microalgal meal were much more expensive than the other feeds, because of the high cost of this raw material (ZK3000/tonne).

Table 24. Feed formulations (expressed as %age of total feed as fed), **Proximate Analysis**(expressed as %age of moisture free weight), **feed costs**(ZK/tonne) **and results from Feed Trial 7.**

Feed number	1	2	3	4	5
Feed Formulations(%)					
Kapenta	20	10	5	10	10
Algae	-	30	40	-	-
Soya oilcake	30	30	30	30	30
Wheatings	45	25	20	25	25
Yeast	5	5	5	5	5
Filamentous algae	-	-	-	30	-
Leucaena	-	-	-	-	30
Raw Material Cost					
(ZK/tonne)	924	1478	1616	878	825
Proximate analysis(%)					
Moisture	12.0	11.4	10.4	9.5	10.7
Crude Protein	24.8	26.6	30.0	29.8	25.8
Ether Extract	8.1	8.9	9.4	9.6	8.5
Crude Fibre	19.0	20.6	21.7	22.5	22.4
Results					
Initial Avge. Wt.(g)	18.9	19.3	20.1	17.4	17.55
Final Avge.Wt.(g)	79.8	73.2	71.9	64.6	81.8
% Mortality	17.2	2.0	3.6	3.0	1.0
Average S.G.R.*	1.46[a]	1.35[a]	1.29[a]	1.33[a]	1.56[a]
Average F.C.R*	2.73[a]	2.55[a]	2.68[a]	2.73[a]	2.31[a]

* calculated as in feed trial 1. Figures in the same row with the same supercsript are not significantly different $P<0.05$. Duncan (1955).

Discussion

This trial would seem to indicate that the plant proteins used, adequately replaced part of the protein supplied by kapenta in feed 1. The high expense of the microalgal meal compared to the other plant protein sources meant that it was too expensive to use in normal production rations. The most promising result was with feed 5, containing leucaena meal. Fish fed this feed grew at similar rates to those fed the control and the feed was also considerably cheaper. Leucaena meal was also starting to become available to the fish farm in much higher quantities than filamentous algae or microalgae.

This would seem to disagree with the findings of Jackson *et al* (1982) who reported that increasing levels of leucaena meal caused marked growth depression in *O. massambicus* fingerlings. Appler and Jauncey(1983) replaced fish meal with filamentous algae (*Cladophora glomerata*) in feeds for *O. niloticus*. Despite growth depression with increasing levels of incorporation of the algae, the conclusion was that algal meals can be viable partial dietary protein sources for tilapias.

7.8. Feed Trial 8. Use of a range of Vitamin C sources.

Introduction

Feed trials 1, 3, 4, 5 and 6 had failed to provide any clear indication that vitamin supplementation of the tilapia feeds was necessary, however work at the University of Stirling on the dietary requirements of tilapias for vitamin C, indicated that high levels were required (Jauncey, Soliman and Roberts, 1985; Soliman, Jauncey and Roberts, 1986(a); Soliman , Jauncey and Roberts, 1986(b)). Feed trial 8 was designed to investigate the dietary requirements of *O. aureus* for vitamin C from a range of sources, vitmin C tablets from the local chemist, in Epoll vitmin mix (see feed trial 4) and from the pulp of baobab fruits (*Adansonia digitata*) which had been reported to contain 370 mg/100g of ascorbic acid (vitamin C) (Anon., 1975).

Materials and methods

Ten test tanks were used for this trial (see feed trial 1) supplied with borehole water (temperature 24 - 25 ^{o}C). Each tank was stocked with approximately 50 *O. aureus* males (hand sexed), all from the same production tank. The fish were allowed to acclimatise for two weeks during which they were fed production fingerling food (see Table 11). Five feeds were made up according to the formulations shown in Table 29, by milling and mixing a single batch of feed containing the raw materials indicated in the feed base. From this batch, 5 individual, 10kg batches were taken, to which were added the vitamin sources. Feed 1 contained no source of vitamins. Feeds 2 and 3 contained 2g and 12.5g of vitamin C tablets respectively (to supply 200mg/kg and 1250mg/ kg vitamin C). Feed 4 contained 50g of Epoll vitamin mix (vitamin C level unknown) and feed 5 contained 88g of baobab pulp which should have supplied 33mg/kg vitamin C.

Each feed was pelleted (Lister pelleter - 4mm die - see section 5.4) , randomly allocated to two tanks and fed at 2% of body weight / day in 3 - 5 hand feeds / day.

Results

The results shown in Table 29, indicate that growth was poor, with specific growth rates ranging from 0.53 - 0.82% / day. Food conversion was also poor (F.C.R. range 2.49 - 4.2). There were no significant differences between treatments.

Table 29. Feed formulations (expressed as % of total feed as fed) **and results from feed trial 8.**

Feed number	1	2	3	4	5
Formulations					
Feed Base(kg)*	13.5	13.5	13.5	13.5	13.5
Vitamin C tablets(g)	-	2	12.5	-	-
Epoll Vitamin Mix(g)	-	-	-	50	-
Baobab Fruit Pulp(g)	-	-	-	-	88
Results					
Initial Avge. Weight(g)	82.4	83.4	95.3	90.9	81.3
Final Avge. Weight(g)	106.9	109.4	125.3	127.9	109.3
% Mortality	0	1	1	0	0
Average S.G.R.**	0.63[a]	0.65[a]	0.65[a]	0.82[a]	0.71[a]
Average F.C.R.**	3.53[a]	3.59[a]	3.52[a]	2.65[a]	3.12[a]

* Feed Base contained: 5kg Kapenta, 3kg Full Fat Soya, 2kg Wheatings, 0.5kg Yeast, 1kg Leucaena, 2kg Bagasse / Molasses.

** calculated as in feed trial 1

Figures in the same row with the same superscript are not significantly different $P<0.05$ (Duncan , 1955).

Discussion

The results of this trial did not agree with those from feeding trials conducted at the University of Stirling. Soliman, Jauncey and Roberts (1986) reported that *O. niloticus* (initial weight 1.2g), fed a basal diet without any form of vitamin C supplementation, showed significantly poorer growth, higher food conversion ratios, haemorrhaging of fins, shortened operculae, caudal fin erosion, exopthalmia, spinal deformities and 40% mortalities when compared with fish fed ascorbic acid supplemented feeds. Whilst it could be argued that the growth rates of fish in the test tanks were not high enough to expose such overt signs of vitamin deficiency, normal production feeds at Nakambala were not being supplemented with vitamins and fish of the same sizes as those used at Stirling were not showing dramatic vitamin deficiency symptoms. If the farm had been suffering from mortality rates of 40% along with the other symptoms of vitamin C deficiency listed above, it would probably have meant that the farm could not continue, as it would have been impossible to obtain regular supplies of ascorbic acid to be used in the feeds at the recommended level of 1250mg/kg.

B Trials carried out in self cleaning tanks on vitamin supply in feeds.

7.9. Feed trial 9. Use of a range of vitamin C sources.

Introduction

The growth rates achieved in feed trials 1 to 8 had been disappointing. Feed trials 1, 3 and 4 and the results from production tanks, had established that *O. macrochir* was unsuitable for intensive culture. Feed trials 5 to 8 used O. aureus, which grew better, but still not as well as, the results which were being achieved with the same fish and similar feeds in production tanks at the rearing unit (see table 6). The conclusion was that the test tanks were unsuitable for tilapia growth. Water flow was uneven because of the rectangular shape, and they were not self cleaning. The shape also encouraged reproductive behaviour by allowing males to establish territories in mixed sex cultures.

As a result of this it was decided that two new tank systems would be set up with round, self cleaning tanks, specifically designed for feed trials. One system was to be for small fish (1g - 20g), the other for larger fish (20g+). The new systems are described in the materials and methods of feed trials 9 and 10. Each system had 12 tanks, which allowed treatments to be carried out in triplicate, making statistical analysis of results easier.

Feed trial 9 was to be carried out in the system for smaller fish (basin tanks) and was to repeat the type of approach used in feed trial 8. Four feeds were to be used, with different vitamin C sources.

Materials and methods

Feed trial 9 was carried out in the basin tanks. These were twelve, 20 litre capacity, round plastic basins (diameter 36cm, water depth 20cm). A diagram is shown in Figure 19. Each tank was supplied with 0.5l/min of borehole water (24 - 25°C), directed tangentially in the tank so that a current was set up. The water level was controlled by a central standpipe with a standpipe cover which caused water to be drawn from the bottom of the tank. This together with the flow created by the inlet, ensured that the tanks were completely self cleaning.

Each tank was stocked with 20, *O. niloticus* of approximately 1.5g average weight. The fish were allowed to acclimatise for one week, during which they were fed production fingerling crumble feeds (see Table 11). Four feeds were formulated as shown in Table 30. The feeds were manufactured by mixing the milled ingredients for a single batch of the feed base. To 1 kg of this base was added the vitamin supplements for each feed. Feed 1 contained no vitamin supplement. Feeds 2 and 3 contained 0.2g and 1.25g of vitamin C tablets respectively (to supply 200mg/kg and 1250 mg/kg vitamin C). 50g of baobabpulp was added to the feed base for feed 4. Each feed was thoroughly mixed, a little water added to make the feed into a stiff dough, and the dough extruded in a hand mincer to make long strings. The strings were dried in warm air from a blower (35°C), broken up using a liquidiser and sieved to pass through a 2mm mesh.

Each feed was randomly allocated to three tanks and fed at 5% of body weight/day in 3 - 5 hand feeds/day. The fish were bulk weighed (Ohaus triple beam scale) following anaesthetisation with benzocaine (1:15000) at the start of the trial and subsequently every fortnight until the end of the trial at 50 days.

Figure 19. The basin tanks.

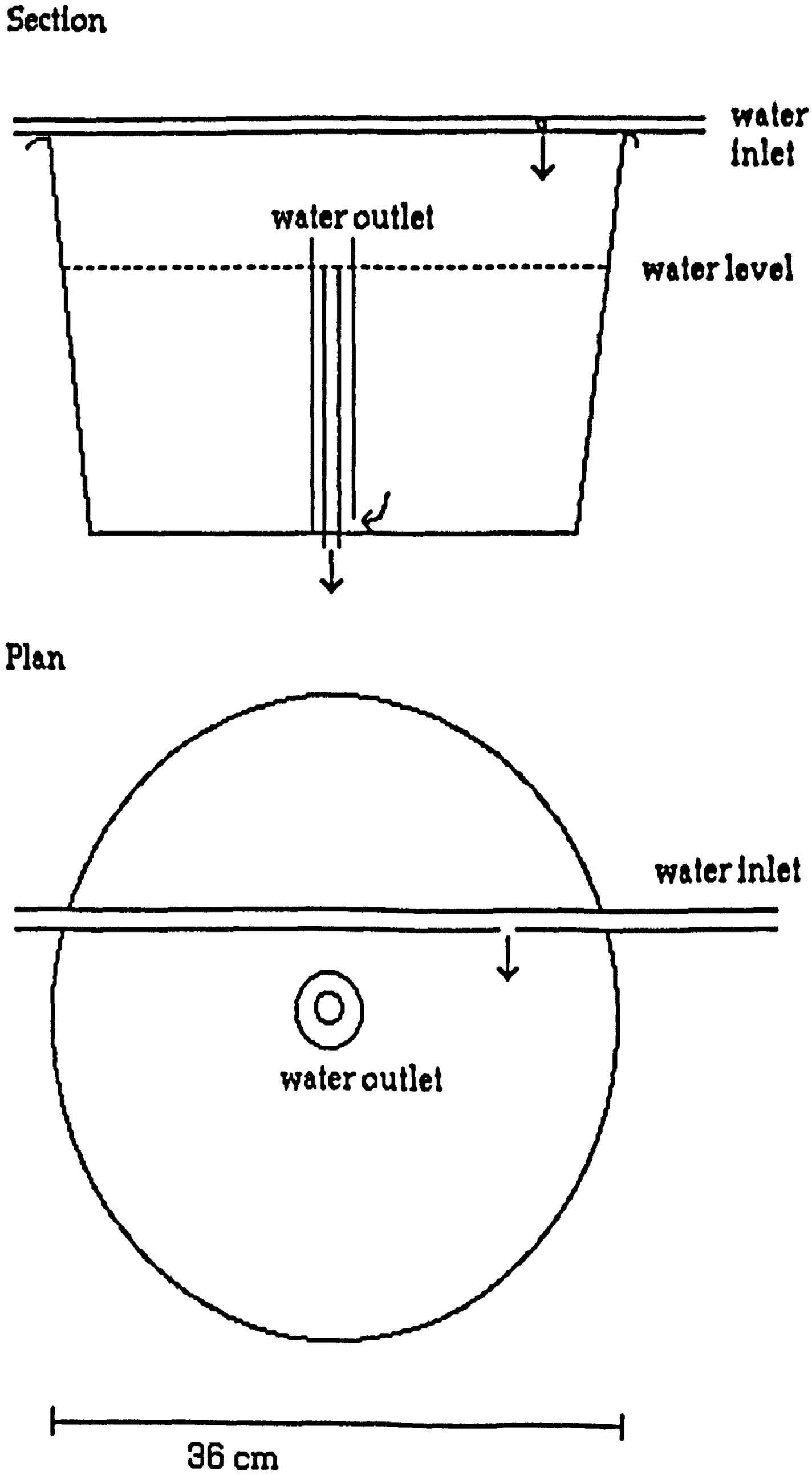


Table 26. Feed formulations and results from feed trial 9.

Feed number	1	2	3	4
Feed Formulations				
Feed Base*(kg)	1	1	1	1
Ascorbicacid(g)	-	0.2	1.25	-
Baobabpulp(g)	-	-	-	50
Results				
Initial Avge.Weight(g)	2.15	1.62	2.18	1.74
Final Avge.Weight(g)	4.69	4.0	5.74	4.29
% Mortality	6.8	5.1	16.9	7.0
Average S.G.R**	1.55[a]	1.82[a]	1.93[a]	1.81[a]
Average F.C.R**	3.97[a]	3.18[a]	3.77[a]	3.46[a]

* Feed base contained: 3kg Kapenta, 3kg lucerne, 2.6kg Yeast, 1kg Bagasse/molasses, 0.4kg Soya oil.

Figures in the same row with the same superscript are not significantly different($P<0.05$; Duncan, 1955).

Results

The results, in table 30, show that growth was disappointing for this size of fish (S.G.R. range 1.46 - 1.97; F.C.R. range 2.65 - 4.16). There was very little difference shown between the treatments. The new tanks worked reasonably well except that the water inlet pipes blocked up with particles of calcium carbonate from time to time, which may have had an adverse effect on growth. Mortality figures were higher than usual because of fish jumping out of the tanks.

Discussion

The results from this feed trial made the vitamin supply situation no clearer. Supplementation of the feeds with vitamin C from a range of sources, did not improve growth.

Two modifications were made to the tank system following this trial. A water filter was fitted on the water inlet to the tanks to remove particles of calcareous material, and each tank was fitted with a cover net to stop fish jumping out.

7.10. Feed trial 10. Vitamin supply in feeds.

Introduction

Although several feed trials had been carried out, it was still unclear whether a vitamin mix was required by tilapias at Nakambala. Following discussions with Dr Jauncey and Tate and Lyle Techical Services, a vitamin premix was formulated by Dr. Jauncey, compounded by Four-F International Ltd., Cambridge, England and supplied by T.L.T.S. The vitamin premix was designed to supply the vitamin levels recommended for tilapia feeds by the University of Stirling and was to be used in a series of feed trials, along with small quantities of individual vitamins which were supplied at the same time, to establish for certain whether growth of tilapias at Nakambala was significantly affected by the supply of vitamins.

Feed trial 10 was to be the first in the series. This was carried out in the outside tanks (described below) with four feeds used in triplicate treatments:

Feed 1 - Basic formulation with no added vitamins.

Feed 2 - Basic formulation with an added vitamin premix.

Feed 3 - Formulation containing 10% luceme and 5% yeast to supply some vitamins in higher levels than in Feed 1.

Feed 4 - Formulation containing 10% luceme and additional individual vitamins to bring the overall vitamin levels close to those recommended for tilapias.

Materials and methods

Feed trial 10 was carried out in the outside tanks. This was a set of twelve tanks,

constructed from mild steel, large diameter, piping from the sugar factory scrap yard. The pipes were cut into lengths of 50cm and set in concrete at one end. A diagram is shown in Figure 20. Each tank had a capacity of 300 litres of water (diameter 1m, water depth 38cm), and was supplied with 6.0 litres/minute of Kafue river water. Water flow into each tank was by a sparge pipe which created a tangential flow of water in the tank. The water level was controlled by a central standpipe with a standpipe cover which caused outgoing water to be drawn from the bottom of the tank. This ensured that the tanks were self cleaning.

Each tank was stocked with 40, *O. aureus*, of approximately 40g average weight, from the same production tank. The fish were allowed to acclimatise for 10 days during which they were fed production grower food (see Table 11), which contained a vitamin premix(see Table 31).

Four feeds were made up according to the formulations shown in Table 31. The raw materials were weighed out, milled and pelleted in the Lister pelleter (see section 5.6), using a 4mm die. Each feed was randomly allocated to three tanks of fish and fed at rates which were reduced from 5% to 3% of body weight/day in 3 - 5 handfeeds/day over the course of the trial. The fish were bulk weighed (Salter top pan balance - anaesthetisation with benzocaine 1:15000) and counted at the start of the trial and at fortnightly intervals until the end of the trial at 56 days, when they were weighed individually (Ohaus triple beam balance following anaesthetisation and surface drying), measured (standard length) and sexed. Condition factor was calculated according to the formula: $C.F. = Weight/(Standard\ Length)^3 \times 100$

Proximate analysis of the feeds was carried out by the National Irrigation research station, Nanga, nr Mazabuka (A.O.A.C. methods; Horwitz, 1980).

Figure 20. The outside tanks.

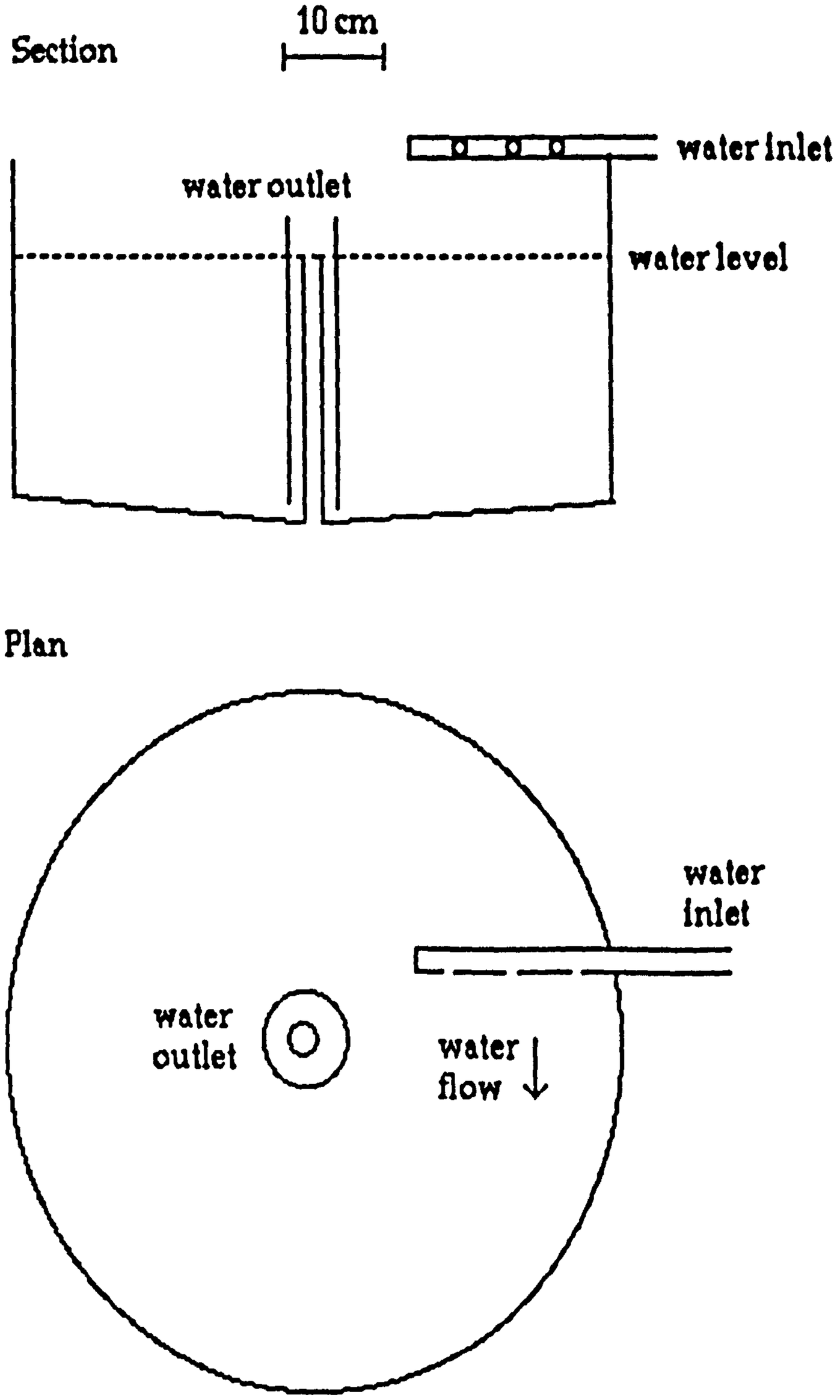


Table 27. Feed formulations(expressed as % of total feed as fed) **and proximate analysis of feeds**(expressed as %age of moisture free weight) **from feed trial 10.**

Feed number	1	2	3	4
Formulations(%)				
Kapenta	25	25	20	25
Full fat soya	20	20	20	20
Sunflower oilcake	20	20	10	10
Wheatings	20	20	20	20
Bagasse/molasses	15	14	15	15
Lucerne	-	-	10	10
Yeast	-	-	5	-
Vitamin Premix*	-	1	-	-
Individual vitamins**	-	-	-	+
Proximate analysis(%)				
Moisture	8.0	7.5	4.4	8.1
Crude Protein	36.2	36.8	36.1	37.4
Ash	11.4	13.2	8.1	9.0

* Tate and Lyle Vitamin Premix containing(/kg of premix): Vitamin A 200000 IU/kg, Vitamin D3 1000000 IU/kg, Vitamin E 10000 IU/kg, Vitamin K 1000 mg/kg, Vitamin B1 1000 mg/kg, Vitamin B2 2000 mg/kg, Vitamin B6 1000 mg/kg, Vitamin B12 100 mg/kg, Nicotinic Acid 2800 mg/kg, Pantothenic acid 2500 mg/kg, Choline chloride 50000 mg/kg, Vitamin C 125000 mg/kg, Folic acid 600 mg/kg, Biotin 100 mg/kg, Inositol 20000 mg/kg, Antioxidant 20000 mg/kg

** Individual vitamins to supply/kg of finished feed: 0.75mg Biotin, 10mg Vitamin B1, 20mg Vitamin B2, 10mg Vitamin B6, 25 IU Vitamin E, 1.25g Vitamin C.

Results

The results displayed in Table 32 show that the fish fed feed 1 (without a vitamin premix), grew as well as the fish fed feeds 2 and 3, and significantly better than the fish fed feed 4. Food conversion ratios followed the same pattern, with the F.C.R. of fish fed feed 1 significantly lower than those fed feed 4, but similar to the F.C.R's for fish fed feeds 2 and 3. There was no significant difference in survival rates or condition factors shown between treatments.

Table 32. Results of feed trial 10.

Feed number	1	2	3	4
Initial Avge. Weight(g)	34.2	35.6	36.2	38.6
Final Avge. Weight(g)	94.2	95.0	92.7	90.7
% Survival	97.5^{a}	96.7^{a}	97.5^{a}	97.5^{a}
Average S.G.R*	1.81^{a}	1.75^{ab}	1.68^{ab}	1.68^{b}
Average F.C.R*	2.01^{a}	2.12^{ab}	2.20^{ab}	2.45^{b}
Average C.F.	3.44^{a}	3.45^{a}	3.34^{a}	3.42^{a}
% female	38.1	38.9	40.4	43.1

Figures in the same row with the same superscript are not significantly different($P < 0.05$; Duncan, 1955).

* calculated as in feed trial 1.

Discussion

The results of this trial are discussed at the end of feed trial 14.

7.11. Feed Trial 11. Vitamin supply in feeds.

Introduction

This trial was to use the same pattern of feeds as was used in feed trial 10, but for smaller *O. niloticus* in the basin tanks.

Materials and methods

Each of the twelve basin tanks(as described in feed trial 9) were stocked with 37 *O. niloticus* of approximately 1g average weight. The fish were allowed to acclimatise for 10 days during which they were fed on production fingerling crumble food whioch contained a vitamin premix.

Four feeds were made up according to the formulations shown in Table 33. The feeds were made up by the hand mincer method described in feed trial 9. Each feed was randomly allocated to three tanks. The fish were fed at rates which reduced from 10% to 5% of body weight/day in 3 - 5 hand feeds/day over the course of the trial. Fish were bulk weighed (Ohaus triple beam scale following anaesthetisation with benzocaine - 1:15000) and counted at the start of the trial and at fortnightly intervals. The trial ended after 81 days when all the fish were individually weighed (as above) and inspected for signs of haemorrhaging. Haemorrhaging was scored according to an arbitrary scale:

0 - no visible haemorrhaging.

1 - haemorrhaging at base of pectoral fin.

2 - haemorrhaging at pectoral fin and mouth.

3 - extensive haemorrhaging at base of all fins and mouth.

Table 28. Feed formulations (expressed as %age of total feed as fed) **and proximate analysis of feeds** (expressed as % of moisture free weight) **from feed trial 11.**

Feed number	1	2	3	4
Feed Formulations(%)				
Kapenta	30	30	25	30
Full fat soya	30	30	30	30
Sunflower oilcake	20	20	10	10
Wheatings	20	19	20	20
Lucerne	-	-	10	10
Yeast	-	-	5	-
Vitamin premix*	-	1	-	-
Individual vitamins**	-	-	-	+
Proximate analysis(%)				
Moisture	8.6	9.3	9.1	7.5
Crude Protein	46.8	47.7	45.6	46.0
Ether Extract	5.5	6.0	6.4	6.0
Crude Fibre	7.1	8.1	8.0	8.4
Ash	6.2	7.1	7.0	6.6

* and ** - as in feed trial 10

Proximate analysis of the feeds was carried out by the National Milling Company, Lusaka, by A.O.A.C. methods (Horwitz,1980).

Results

The results are shown in Table 34. Fish fed feed 1 (without vitamin supplementation) grew significantly better than fish fed feed 4 and at a similar rate to those fed feeds 2 and 3. There was no significant difference between food conversion ratios or survival rates of fish fed on the four feeds. The average degree of haemorrhaging was significantly higher in fish fed feed 1.

Table 34. Results of feed trial 11

Feed number	1	2	3	4
Initial Avge. Weight(g)	0.81	1.05	0.95	0.98
Final Avge. Weight(g)	5.26	6.58	6.03	5.93
% Survival	67.6[a]	80.8[a]	81.1[a]	88.3[a]
Average S.G.R.*	2.31[a]	2.26[ab]	2.25[ab]	2.22[b]
Average F.C.R.*	3.09[a]	3.04[a]	3.00[a]	3.03[a]
Average Haemorrhaging	1.69[a]	0.59[b]	0.78[b]	0.62[b]

Figures in the same row with the same superscript are not significantly different($P < 0.05$; Duncan, 1955).

* calculated as in feed trial 1

Discussion

This trial is discussed at the end of feed trial 14.

7.12. Feed Trial 12. Vitamin supply in feeds.

Introduction

This trial used the same pattern of feeds as was used in feed trials 10 and 11,for *O. niloticus* of intermediate size, in the outside tanks.

Materials and methods

Each of the 12 outside tanks were stocked with 70 *O. niloticus* of approxdmately 8g average weight from the same production tank. The fish were allowed to acclimatise for 13 days, during which they were fed fingerling crumble production food, with a vitamin premix (see Table 11).

Four feeds were made up to the formulations shown in Table 35 by the same methods as were used in feed trial 10. After pelletisation, the feeds were crumbled in a hand grinder and sieved to pass through a 3mm mesh. Each feed was randomly allocated to three tanks and fed at rates which were reduced from 6 to 4% of body weight / day in 3 - 5 hand feeds / day over the course of the trial.

The fish were bulk weighed (Salter top pan scale) following anaesthetisation with benzocaine (1:15000) and counted at the start of the trial and subsequently at fortnightly intervals. The trial ended after 70 days when the fish were individually weighed (Ohaus triple beam scale following anaesthetisation).

A sample of each feed was subjected to proximate analysis at the National Milling Company, Lusaka (A.O.A.C. methods; Horwitz, 1980).

Table 35. Feed formulations (expressed as %age of total feed as fed) **and proximate analysis**(expressed as % of moisture free weight) **of feeds from feed trial 12.**

Feed number	1	2	3	4
Feed Formulations(%)				
Kapenta	10	10	10	10
Blood Meal	15	15	10	15
Full fat soya	20	20	20	20
Sunflower oilcake	20	20	10	10
Wheatings	20	20	20	20
Bagasse/molasses	15	14	15	15
Lucerne	-	-	10	10
Yeast	-	-	5	-
Vitamin premix*	-	1	-	-
Individual vitamins**	-	-	-	+
Proximate analysis(%)				
Moisture	8.5	8.2	8.5	9.0
Crude Protein	43.2	40.4	37.2	40.7
Ether Extract	6.6	6.8	7.1	6.8
Crude Fibre	10.5	10.3	10.8	10.5
Ash	7.0	7.4	7.4	7.5

* and ** - as in feed trial 10.

Results

The results in Table 36 show that fish fed feed 1 (without the vitamin supplement) had similar specific growth rates to fish fed feeds 3 and 4 and significantly higher growth rates than fish fed feed 2 (containing the Tate and Lyle vitamin premix). The food conversion ratios of fish fed feeds 1 and 3 were significantly lower than those of fish fed feed 2 and similar to the F.C.R's of fish fed feed 4. There was no significant difference in survival rates between the different treatments.

Table 36. Results of feed trial 12

Feed number	1	2	3	4
Initial Avge. Weight(g)	9.44	9.51	9.67	9.90
Final Avge. Weight(g)	32.0	29.4	31.2	31.6
% Survival	96.6^{a}	98.1^{a}	97.1^{a}	98.1^{a}
Average S.G.R.*	1.74^{a}	1.61^{b}	1.67^{ab}	1.66^{ab}
Average F.C.R*	2.50^{a}	2.69^{b}	2.52^{a}	2.56^{ab}

Figures in the same row with the same superscript are not significantly different($P < 0.05$; Duncan , 1955).

* calculated as in feed trial 1.

Discussion

These results will be discussed at the end of feed trial 14.

7.13. Feed trial 13. Vitamin supply in feeds.

Introduction

In addition to the feed trials conducted in the experimental systems using the Tate and Lyle vitamin premix, it was felt that it would be useful to carry out a trial in two of the production tanks in the rearing unit.

Materials and methods

Approximately 5000 *O. niloticus* of approximately 10g average weight were stocked into each of two production tanks (see section 2.3). Tank 1 was fed normal fingerling crumble food (see table 11) containing Tate and Lyle vitamin premix (see table 31). Tank 2 was fed feeds of the same formulation but without the vitamin premix. The feeds were prepared using normal methods (see sections 5.6 and 5.6). When the fish passed 30 g average weight, the feed was changed to pelleted grower food.

A sample of at least 100 fish from each tank was bulk weighed (Salter hanging scale following anaesthetisation with benzocaine, 1:15000) every 14 days and rations adjusted accordingly. Feeding rates were reduced from 6.5% to 3.2% of body weight/day over the course of the trial. Feeding was by a combination of demand and hand feeding throughout daylight hours. After 92 days over 100 fish from each tank were individually sexed, weighed and measured (Standard Length). On the following day a further sample of 30 fish was taken from each tank and dissected to establish sex and level of maturity.The trial ended after 98 days. Maturity was assessed according to the scale: 1 - immature; testes or ovaries undeveloped.

2 - intermediate

3 - mature: testes or ovaries fully developed.

Results

The average weights of samples taken from the tanks over the 98 day period are displayed in Figure 21. Overall results are shown in Table 37.

Growth was excellent for the first ten weeks, but then slowed probably due to lower water temperatures. By the end of the experiment the fish fed the vitamin mix appeared to be growing slightly better than those without, although the difference could have been due to sampling error.

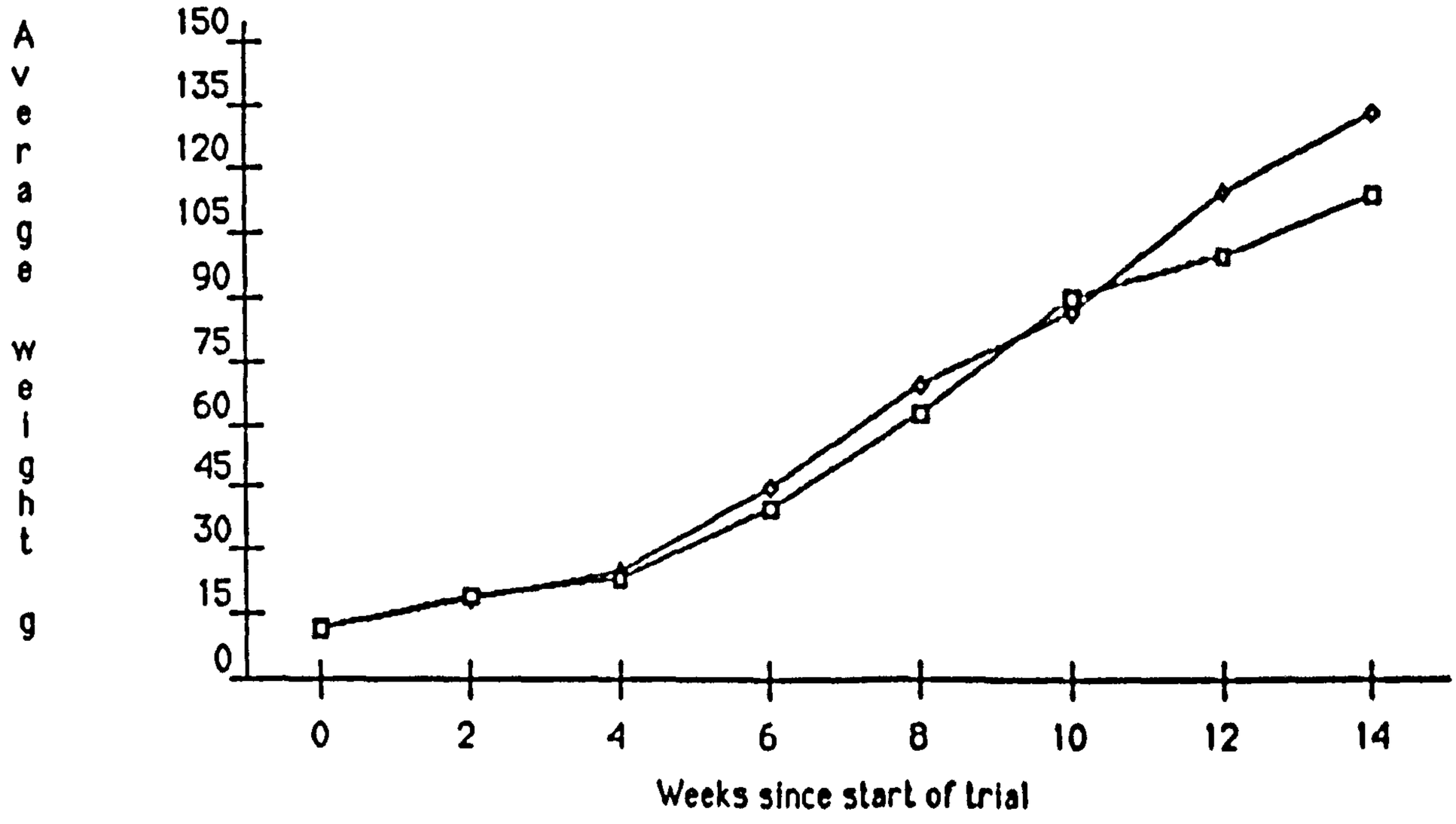
The results of samples taken at 92 days are displayed in Table 38. These show very little difference in average weights or condition factors between the two tanks. The fish in tank 1 showed greater variability in size indicated by the higher standard deviation of weights. It was thought that this may have been due to a higher percentage of females in the sample from tank 1, but when the data were split between the sexes the higher degree of variability was shown by both males and females.

Table 37. Results of Feed Trial 13. I. Data from fortnightly samples.

	1	2
Treatment	With vitamin premix	Without vitamin premix
Initial Average Weight(g)	11.3	11.3
Final Average Weight(g)	132.9	114.2
Average Weight Gain(g/day)	1.24	1.05
S.G.R after 10 weeks*	2.93	2.97
S.G.R after 14 weeks*	2.52	2.36
Overall F.C.R*	1.95	2.18
Survival(%)	99.6	99.7

* calculated as in feed trial 1.

Figure 21. Results of the feed trial in production tanks. Average weights of samples from tanks 1 & 2 over 98 days.



Tank 1 = fish fed a feed with vitamin premix

Tank 2 = fish fed a feed without vitamin premix

Table 38. Results from feed trial 13. II. Data from samples taken after 92 days.

	1	2
Treatment	With vitamin premix	Without vitamin premix
Average Weight(g+/- standard deviation)	115.5+/-35.2	113.3+/-29.2
Average Condition Factor	4.21	4.23
No. of Females in Sample	48	40
Average Weight of Females(g+/-s.d.)	97.6+/-28.8	97.1+/-24.0
No. of Males in Sample	54	63
Average Weight of Males(g+/-s.d.)	131.5+/-32.7	123.6+/-27.7

The results of the fish sampled and dissected to establish level of maturity are shown in Table 32. This was carried out to see whether the higher degree of variability in size in tank 1 was due to fish maturation in response to adverse condition caused by a shortage of vitamins. The results indicate that females in tank 1 seemed to be more mature than those in tank 2, wheras for males, those in tank 2 had a higher degree of maturity than those in tank 1. It would be useful to have a more precise means of determining maturity before any firm conclusions could be drawn from this.

Table 32. Results from Feed Trial 13. III. Data from samples dissected after 93 days to establish level of maturity.

	1	2
Treatment	With vitamin premix	Without vitamin premix
Average Weight(g+/-standard deviation)	117.3+/-32.5	116.9+/-31.0
Average degree of maturity(+/- s.d.)	1.77+/-0.72	1.78+/-0.75
Avge. degree of maturity for males(+/- s.d.)	1.94+/-0.68	2.05+/-0.69
Avge. degree of maturity for females(+/- s.d)	1.60+/-0.74	1.33+/-0.65

7.14. Feed Trial 14. Vitamin supply in feeds.

Introduction

The preceding trials (10 - 13) seemed to indicate that there was no need for a vitamin supplement in the tilapia feeds. One of the possible sources of vitamins available to a fish is from gut microbial synthesis (Lovell and Limsuwan, 1982). Feed trial 14 was to determine whether this was a possible source of vitamins for the tilapias at Nakambala by feeding an antibiotic, which should reduce gut microbial activity and remove this possible source of vitamins.

Materials and methods

Each of the 12 outside tanks (see feed trial 10) were stocked with 40 *O. niloticus* of around 40g average weight from a sngle production tank. The fish were allowed to acclimatise for two weeks, during which they were fed production grower feeds (see Table 11).

Four feeds were made up according to the formulations shown in Table 40. Feed 1 contained a normal formulation with the Tate and Lyle vitamin premix. Feed 2 was of the same formulation but did not contain the premix. Feeds 3 and 4 were the same as Feeds 1 and 2 respectively, except that they contained an antibiotic (Tetracycline - see Table 40). The feeds were prepared by splitting a single feed batch, adding the vitamin supplement and/or antibiotic, remixing and pelleting in the Lister pelleter (see section 5.6).Each feed was randomly allocated to three tanks and fed at 3.5% of body weight/day in 3 - 5 hand feeds/ day. The fish were bulk weighed (Salter hanging scale, anaethetisation with benzocaine; 1:15000) and counted at the start of the experiment, at 14 days, 28 days and at the end of the experiment after 36 days.

Results

Results are shown in Table 40. The fish grew reasonably well with average feed conversion ratios below 2 and S.G.R's between 1.69 and 2.08, however there were no significant differences in growth rates or food conversion between fish on the different treatments. This may indicate that microbial synthesis of vitamins is unimportant in tilapias, however the dosage rates used for the antibiotic were scaled from dosages recommended for the treatment of gut disorders in piglets. This may not be a high enough dose to inactivate the vitamin synthesising micro-organisms in the tilapias. It may be possible to check on the microbial activity of the gut by microbiological methods. Unfortunately this was not available to us at Nakambala.

Table 33. Feed formulations (expressed as %age of total feed as fed) **and results from feed trial 14.**

Feed number	1	2	3	4
Feed Formulations				
Feed Base(kg)*	10	10	10	10
Vitamin supplement(g)**	100	-	100	-
Antibiotic(g)***	-	-	50	50
Results				
Initial Average Weight(g)	39.3	39.7	37.5	38.9
Final Average Weight(g)	75.1	78.3	73.1	76.5
% Survival	100	100	99.2	100
Average S.G.R.	1.80	1.88	1.85	1.88
Average F.C.R.	1.99	1.88	1.95	1.91

*Feed Base contained: 10% Kapenta, 10% Blood meal, 20% Full fat soya, 20% Sunflower oilcake, 40% Wheatings.

**Tate and Lyle Vitamin Supplement as used in Feed Trials 10 - 13.

*** Tetracycline - T.A.D. Pharmazeutisches, Werk GmBH, West Germany. - recommended dosage for piglets 6g/20kg body weight/day.

Discussion of feed trials 9 to 14.

Vitamins are organic compounds required in trace amounts for the functioning of most forms of life, but which some animals are unable to synthesise. Four sources of vitamins are available to tilapias in intensive culture:

(1) In the feed. Table 41 gives the estimated vitamin contents of the experimental feeds used in Feed Trial 11 (those in trials 10 and 12 would be similar), expressed as a percentage of the levels recommended by the University of Stirling. As can be seen, feeds containing no vitamin supplement, contain appreciable levels of vitamins, indeed some of the vitamins are supplied in excess of the estimated requirements for tilapias. However it should be noted that the formulated vitamin levels supplied by the raw materials or vitamin premixes may be very different from the levels which are available to the fish because of interactions with other feed ingredients, losses in processing of the feed and losses by leaching in water (Slinger, Razzaque and Cho, 1979; Soliman, Jauncey and Roberts, 1987). It may be possible in some situations that the fish are able to derive significant amounts of vitamins from phytoplankton in the water. This was unlikely in these experiments because the water source did not contain high phytoplankton levels.

(2) From storage in fish tissues. Water soluble vitamins are not stored in large amounts but fat soluble vitamins can be (NRC, 1983). If fish had been fed a vitamin rich diet and then fed a vitamin deficient diet, stores of fat soluble vitamins should be available for some time whereas stores of water soluble vitamins will rapidly become depleted.

(3) Produced by the fish. Synthesis of inositol has been demonstrated in the liver of channel catfish (NRC, 1983). Synthesis of ascorbic acid has been shown in the liver and

Table 41. Estimated vitamin levels in the experimental feeds expressed as %age of the estimated requirements of tilapias. (Derived from N.R.C.[1983] and McDonald *et al* [1981]).

Feed Number	1	2	3	4
Water Soluble Vitamins				
Vitamin B1	74	100+	100+	100+
Vitamin B2	17	100+	29	100+
Vitamin B6	N/A	100+	N/A	100+
Pantothenic acid	58	100+	79	58
Niacin	100+	100+	100+	100+
Biotin	17	100+	24	95
Folic acid	18	100+	29	21
Vitamin B12	6	100+	10	6
Choline	100+	100+	100+	100+
Inositol	N/A	100+	N/A	N/A
Vitamin C	N/A	100+	N/A	100+
Fat Soluble Vitamins				
Vitamin A	18	100+	100+	100+
Vitamin D	N/A	100+	N/A	N/A
Vitamin E	17	100+	26	51
Vitamin K	0	100	9	9

N/A - Figure not available

100+ - vitamin supplied in excess of the estimated requirements for tilapias.

kidney of common carp, *Cyprinus carpio* L, and in the kidney of *Oreochromis aureus* and *Oreochromis spilurus* (Gunther) (Soliman, Jauncey & Roberts, 1985).

(4) Produced by the intestinal microflora. Gut microbial synthesis of biotin (channel catfish), folic acid (carp), vitamin B_{12} (channel catfish and tilapia) and inositol (channel catfish) have been demonstrated (Lovell &Limsuwan, 1982; NRC, 1983). The contribution in an omnivorous fish such as a tilapia may be significant.

None of the feed trials demonstrated that inclusion of the vitamin premix in the diet resulted in improved growth. This suggests that either the vitamin requirements of tilapias have been greatly overestimated or that vitamins are available to tilapias, fed a vitamin deficient diet, from one of the above sources.

The only evidence of deficiency was in feed trial 11, when fish fed diet 1 showed higher levels of haemorrhaging than fish fed the other feeds. If it is assumed that biotin, folic acid, vitamin B_{12}, inositol and ascorbic acid can be supplied by visceral or gut microbial synthesis and that choline, vitamin D and vitamin K are not required in tilapias (other studies have provided no clear evidence that they are required in other fish (NCR, 1983)), then according to Table 41, vitamin E, vitamin A and riboflavin are the most critically deficient vitamins in diet 1. Fish fed diet 3 in the same feed trial did not show high levels of haemorrhaging. The main difference between these feeds was the supply of vitamin A by luceme in diet 3. Stickney (1979) included haemorrhaging as one of the main indicators of vitamin A hypovitaminosis.

In feed trials 10 and 12 no overt signs of vitamin deficiency were observed. The fish used in these trials were larger and the trial duration shorter than in feed trial 11. The fish fed the vitamin deficient diets in these trials may have carried adequate stores of vitamin A (a fat soluble vitamin) at the start of the trial to last until the end.

In the feed trial in production tanks the feed formulations varied according to the availability of feed ingredients. For most of the time these would have included luceme or leucaena, which would have supplied adequate quantities of vitamin A to those fish not fed a vitamin premix.

Feed trial 14 was designed to show if microbial synthesis of vitamins was important. If it can be assumed that the microbes were inactivated by the antibiotic dosage used, then it would appear that this source of vitamins is unimportant to these fish. It would have been useful to have carried out microbiological analysis of the gut contents of treated and untreated fish to determine whether the gut bacteria were killed by the antibiotic.

The vitamin premix used in these experiments added an extra ZK283/tonne or approximately 25% to raw material feed costs excluding the cost of freight and the inconvenience of buying in foreign exchange. The experiments indicated that it was not worthwhile to include the premix as inclusion did not result in improved fish performance to offset the significant increase in costs.

These experiments highlight the paucity of information on the detailed nutritional requirements of tilapias. Recent work in Israel (Viola and Zohar, 1986), has come to the same conclusion, that tilapias in intensive culture do not require vitamin supplementation of the diet, but the work has only been published in Hebrew to date. This work did not suggest where the vitamins were being obtained from. Lovell and Limsuwan (1982) indicated that there were significant differences between the rates of intestinal synthesis of vitamin B_{12} in different fish species and suggested that the requirements for other vitamins may vary in a similar way. Vitamin requirements may also vary between different sizes of fish, as is evident with other animals

(McDonald, Edwards & Greenhaugh, 1981). Larger fish with a better developed gut microflora would be expected to have lower vitamin requirements. On a farm, the large fish consume most of the food. Lowering the feed costs for them would result in considerable savings on the overall feed bill.

Identification of the most critical vitamins in each case would allow the formulation of specific vitamin mixes for use with particular feed formulations and fish. The problem at present is that this would require a great deal of research effort, which would only be of benefit to tilapia farmers in countries such as Zambia where the shortage of foreign exchange is so critical. In other countries where it is possible to include vitamin premixes in the diets, even if it was conclusively proven that a vitamin premix was not required in feeds for tilapias, feed formulators for feed manufacturers would still include a premix in the formulation. To leave it out would probably lead to litigation of the feed manufacturer in the event of there being growth problems on a farm.

C. Trials carried out in self cleaning tanks on other subjects.

7.15. Feed Trial 15. The use of leucaena and luceme to replace animal protein.

Introduction

Although by the middle of 1986, the feeds being produced at Nakambala were capable of sustaining good fish growth, there were still problems in supplying sufficient quantities of animal protein in the feeds. Feed trial 7 had identified that leucaena was a promising feed ingreient, and following the establishment of plots of lucerne and leucaena near the fish farm, increasing quantities of these legumes were becoming available for use in the feeds. Feed trial 15 was to investigate whether lucerne and leucaena could replace some of the animal protein used in the feeds.

Materials and methods

Each of the basin tanks (see feed trial 9) was stocked with 20, *O. niloticus* of around 4g average weight. The fish were allowed to acclimatise for two weeks during which they were fed production fingerling crumble (see table 11). Four feeds were made up according to the formulations shown in Table 42, by mixing the milled ingredients and pelleting in the Lister pelleter (see section 5.6). The feeds were crumbled before use, in a hand grinder, and sieved to pass through a 3mm mesh. Feed 1 contained 15% kapenta and 15% meat and bone meal. In feeds 2 and 3 a proportion of these ingredients were replaced by 10% luceme meal and 10% leucaena meal respectively. Feed 4 contained 10% luceme and 10% leucaena, replacing a greater proportion of the animal proteins.

Each feed was randomly allocated to three tanks and fed at 4.5% of body weight/day in 3 - 5 feeds/day. At the start of the experiment the fish were bulk weighed (Ohaus triple

beam scale, anaesthetisation with benzocaine - 1:15000) and counted. The fish were reweighed at fortnightly intervals and at the end of the experiment after 56 days. A sample of each feed was taken for proximate analysis by the National Milling Company, Lusaka (A.O.A.C. methods; Horwitz, 1980)

Results

The results are shown in Table 35. Growth was consistently good in the fish fed feed 1 (no leucaena or lucerne), but was rather variable for fish fed the other three feeds. The specific growth rates and feed conversion ratios of the fish fed feed 1 were significantly better than those fed feeds 2 and 4, but not significantly better than those fed feed 3. Comparison of the fish fed feeds 2, 3 and 4 showed that there was no significant difference between them.

Discussion

The results indicate that substitution of animal protein can be carried out with leucaena and lucerne, however there may be a slight effect on growth. It was interesting that there was no significant difference in the response of fish between diets 2 and 3, considering the widely reported problem of mimosine in leucaena. This would seem to indicate that leucaena was just as good a protein source as lucerne. As was pointed out in section 5.7., the feeds were generally deficient in methionine. Replacement of kapenta and carcase meal(methionine level 1.4% of protein in both) with leucana (methionine level 0.6% of protein) and lucerne (methionine level of 0.4% of protein) will have made the deficiency worse. This may account for the difference in growth between the control and the other feeds. Jackson *et al* (1982) and Cruz and Laudencia (1978) encountered poor growth responses in tilapias fed diets containing leucaena.

Table 42. Feed formulations (expressed as %age of total feed as fed), **proximate analysis of feeds** (expressed as % composition of moisture free weight) **and results of Feed Trial 15.**

Feed number	1	2	3	4
Feed Formulations(%)				
Kapenta	15	12.5	12.5	10
CarcaseMeal	15	12.5	12.5	10
Full Fat Soya	25	25	25	25
Sunflower Oilcake	12.5	12.5	12.5	12.5
Wheatings	31.8	26.8	26.8	21.8
Lucerne	-	10	-	10
Leucaena	-	-	10	10
Vitamin Premix*	0.7	0.7	0.7	0.7
Proximate Analysis(%)				
Moisture	9.6	7.1	7.6	7.5
Crude Protein	29.2	28.3	30.4	32.6
Ether Extract	11.8	8.9	11.2	9.1
Crude Fibre	4.4	10.3	3.6	5.2
Ash	10.3	11.2	9.3	9.5
Results				
Initial Avge. Weight(g)	3.9	4.0	4.0	3.8
Final Avge. Weight(g)	15.1	12.9	12.1	10.9
% Survival	97.3	96.0	98.7	96.0
Average S.G.R.	2.40^{a}	2.10^{b}	1.97^{ab}	1.89^{b}
Average F.C.R.	2.16^{a}	2.46^{b}	2.75^{ab}	2.74^{b}

* Tate and Lyle Vitamin premix as in Feed Trials 10 - 14.

Figures in the same row with the same superscript are not significantly different ($P < 0.05$; Duncan ,1955).

7.16. Feed Trial 16. The use of different high carbohydrate feed materials.

Introduction

Feed trial 16 compared the response of medium sized tilapias to changes in the main carbohydrate source in the feeds. Over the course of the project at Nakambala a number of feed base materials had been used. Usually the change from one to the other had been as a result of necessity because of shortage or price. As pointed out in Chapter 4, these had a profound influence on pelleting characteristics. This feed trial was designed to see if they also had an effect on growth. The four base materials were sorghum, maize, wheatings and bagasse/molasses.

Materials and methods

Each of the outside tanks were stocked with 40, *O. niloticus* of approximately 25g average weight, from a single production tank. The fish were allowed to acclimatise for three weeks, during which they were fed normal production grower food(see Table 11).

Four feeds were made up, each containing a different feed base material. Formulations of each were adjusted to allow for variation in the protein contents of each of the raw materials. The feeds were formulated to supply 28% crude protein. In feed 1, sorghum was the main carbohydrate source, in feed 2 it was maize, feed 3 was wheatings and feed 4 a 1:3 mix of bagasse:molasses was used. As can be seen from Table 43, the formulations were adjusted to allow for the differing protein contents of the carbohydrate sources. The raw materials for each feed were weighed out, milled and mixed before pelleting in the Lister pelleter (see section 5.6) with a 4mm die.Each feed

was randomly allocated to three tanks and fed at 3.5% of body weight/day in 3 - 5 feeds/day.

The fish in each tank were bulk weighed(Salter hanging scales, anaesthetisation with benzocaine, 1:15000) and counted at the start of the trial, and subsequently every fortnight until the end of the trial after 56 days.

Table 36. Feed formulations (expressed as % of total feed as fed) **and proximate analysis of feeds** (expressed as % of moisture free feed) **from feed trial 16.**

Feed number	1	2	3	4
Feed Formulations(%)				
Kapenta	6.67	6.67	6.67	6.67
CarcaseMeal	8	8	8	8
Full Fat Soya	13.33	15.07	10.53	22.9
Sunflower Oilcake	13.33	13.33	13.33	13.33
Lucerne	10	10	10	10
Leucaena	10	10	10	10
Sorghum	37.7	-	-	-
Maize	-	35.87	-	-
Wheatings	-	-	40.53	-
Bagasse/Mollasses	-	-	-	28
Vitamin Premix(T & L)	0.93	0.93	0.93	0.93
Proximate Analysis(%)				
Moisture	8.8	9.8	9.2	10.8
Crude Protein	27.4	22.5	28.3	25.8
Ether Extract	8.8	8.4	8.0	7.8
Crude Fibre	7.2	7.8	8.8	12.4
Ash	8.8	7.3	8.5	11.0

A sample of each feed was taken for proximate analysis at the laboratory of the National Milling Company, Lusaka. (A.O.A.C. methods; Horwitz, 1980).

Results

The results, shown in Table 44, indicate that there was no significant difference in growth or feed conversion between fish fed the different feeds, however growth was not particularly good, with an average S.G.R. over the twelve tanks of 1.23. Food conversion ratios ranged from 2.83 - 3.39. Proximate analysis of the feeds revealed that the crude protein content of feed 2(based on maize) was much lower than the crude protein contents of the other feeds.

Table 44. Results of feed trial 16.

Feed number	1	2	3	4
Initial Avge.Weight(g)	27.1	27.1	29.3	26.5
Final Avge. Weight(g)	57.5	51.9	58.0	52.5
% Survival	95.8	99.2	98.3	99.2
Average S.G.R*	1.34[a]	1.15[a]	1.22[a]	1.22[a]
Average F.C.R*	2.83[a]	3.35[a]	3.39[a]	2.92[a]

Figures in the same row with the same superscript are not significantly different($P < 0.05$; Duncan, 1955).

* calculated as in feed trial 1.

Discussion

The main conclusion to be taken from this experiment was that the fish seemed to be very adaptable with regard to the carbohydrate source of their feed. It is therefore reasonable to make decisions on which carbohydrate source to use, based upon factors such as availability and price. Viola and Arieli (1983(b)), using *O.aureus* x *O.niloticus* hybrids held in cages, found that fish fed a diet containing 65 - 75% sorghum grew 10 - 15% better than those fed wheat and corn (maize) based diets and similarly to fish fed a diet based on a mixture of bran and corn. The S.G.R's in these experiments ranged from 0.75 - 1.05, however the fish used were also larger (start weights 190 - 200g) than those used in fed trial 16.

The most unusual raw material in this feed trial was the mixture of bagasse and mollasses (see Chapter 4 for details on manufacture). This was used for a period of time in production feeds as an emergency measure when the supply of wheatings stopped. This trial demonstrated that it could adequately replace the more conventional ingredients.

No tests were carried out on the water stability or hardness of the pellets, although these factors were undoubtedly affected. The water stability of pellets depends on the raw materials used and the process applied. Viola, Gur and Zohar (1985) found that a steam pelleted sorghum pellet was over 4 times more water stable than one pelleted without steam, and a wheat based pellet was approximately 5 times more stable than a sorghum based pellet produced under similar conditions. Nevertheless, in feed trials using these pellets in tilapia ponds, pellet stability could not be correlated with increased fish growth rate. In intensive tanks, water stability of pellets is likely to be

even less important, as the pellets are normally consumed immediately on entering the water. Pellets which are too hard may be spat out by tilapias and allowed to soften before being consumed (Dickson, 1981). In a self cleaning tank or cage, the pellets could easily be lost before they are soft enough to be eaten.

Amino acid analysis of the feeds was not carried out in feed trial 16, however subsequent analyses on the raw materials showed that the amino acid balance in the different grains was quite different (see Table 9). Amino acid analysis of production feeds showed that they were deficient in methionine when compared to the estimated amino acid requirements of tilapias (see Table 2). Sorghum contained roughly 10 times more methionine than wheatings. Use of sorghum instead of wheatings could have made a useful contribution to the amino acid balance of the production feeds, however it must be stressed that the amino acid analyses were the result of only one set of samples.

7.17. Feed Trial 17. Kapenta, blood meal and oilseeds as protein sources.

Introduction

Kapenta and blood meal became the principal animal protein ingredients in the production feeds in 1986 (see Table 11), because they were available at reasonable prices and were easily used. At times there were shortages of one or the other, leading to situations where production feeds had to be made containing only kapenta or only blood meal as the animal protein source in the feeds. Feed trial 17 was to compare the effects of using kapenta and blood meal, and whether their use could be reduced by replacement with protein from oilseeds.

Materials and methods

Each of the basin tanks (see feed trial 9) was stocked with 20 *O. niloticus* of approximately 4g average weight. The fish were allowed to acclimatise for three weeks, during which they were fed production fingerling crumble feeds (see Table 11). Four feeds were made up as shown in Table 45. Feed 1 contained kapenta as its sole animal protein source. Feed 2 contained blood meal, feed 3 contained equal quantities of both and feed 4 replaced some of both with full fat soyabeans and sunflower oilcake. The formulations were adjusted to balance the protein levels in the feeds. The ingredients for each feed were weighed out, mixed and milled, then pelleted with the Lister pelleter (see section 5.6). The pellets were then crumbled using a hand grinder and sieved to pass through a 2mm mesh. Each feed was allocated randomly to three tanks and fed at 4.5% of body weight/day in 3 - 5 hand feeds/day.

The fish were bulk weighed (Ohaus triple beam scale, anaesthetisation with benzocaine 1:15000) and counted at the start of the trial, subsequently at fortnightly intervals and at the end of the trial after 28 days.

Proximate analysis of each feed was carried out by the laboratory of the National Milling Company, Lusaka (A.O.A.C. methods; Horwitz, 1980).

Table 37. Feed formulations (expressed as % of total feed as fed) **and proximate analysis of feeds** (expressed as % of moisture free weight in feed) **in feed trial 17.**

Feed number	1	2	3	4
Feed Formulations(%)				
Kapenta	25	-	10.25	4.85
Blood Meal	-	17.4	10.25	4.85
Full Fat Soya	20	20	20	40
Sunflower Oilcake	10	10	10	20
Lucerne	10	10	10	10
Wheatings	34	41.6	38.5	19.3
Vitamin Premix*	1	1	1	1
Proximate Analysis(%)				
Moisture	6.7	7.2	6.7	6.8
Crude Protein	38.1	35.0	36.3	37.3
Ether Extract	8.0	6.3	7.2	10.5
Ash	9.3	6.3	6.7	7.5

* Tate and Lyle vitamin premix as in feed trial 10.

Results

Table 46 shows the results. Best growth (S.G.R. = 3.49) and feed conversion (F.C.R. = 1.34) was shown by those fish fed feed 1, containing only kapenta as an animal protein source. Replacement of half the kapenta with blood meal, in feed 3, resulted in significantly lower growth and poorer feed conversion. Total replacement of kapenta with blood meal resulted in even worse growth and food conversion. The fish fed feed 4, in which over 60% of the animal protein had been replaced by protein supplied by soya and sunflower oilcake, grew as well as the fish fed feed 3 (containing kapenta and blood meal) and significantly better than fish fed feed 2 (containing only blood meal).

Table 46. Results of feed trial 17.

Feed number	1	2	3	4
Initial Avge. Weight(g)	3.83	3.94	4.24	3.78
Final Avge. Weight(g)	10.21	7.67	9.22	7.90
% Survival	100	97.7	98.9	87.4
Average S.G.R.*	3.49^{a}	2.37^{c}	2.77^{b}	2.64^{b}
Average F.C.R.*	1.34^{a}	2.15^{c}	1.74^{b}	2.17^{c}

Figures in the same row with the same superscript are not significantly different($P < 0.05$; Duncan, 1955).

* calculated as in feed trial 1.

Discussion

The main conclusions to be drawn from this trial were that kapenta is a better source of animal protein than blood meal and that oilseeds effectively replaced animal protein in a feed which contained both kapenta and blood meal. Replacement of kapenta with blood meal resulted in a clear diminution of growth. Otubusin(1987) found that increasing levels of blood meal resulted in reduced growth with *O. niloticus* held in cages, although he suggested that this was due to excessively high protein levels in the feeds. Although the protein content of blood meal is high (92.6% in Table 9), the amino acid balance is rather biased (Gohl, 1981). Blood meal also contains significant quantities of crude protein which is not in the form of amino acids (non protein nitrogen) (Jauncey, personal communication).

The results from the fish fed feed 4 indicated that the oilseeds were able to replace part of the animal proteins with no significant effect on growth. Viola and Arieli (1983) reported that soybean meal could replace up to half of the fishmeal in tilapia feeds of 25% protein content, however Shiau et al (1987) suggested that soybean meal could only replace fish meal in diets for *O.niloticus x O. aureus* hybrids,which contained suboptimal (24%) protein levels. Diets containing higher (32%) protein levels needed to be supplemented with methionine for growth to be comparable with fish fed all fish meal feeds.

7.18. Conclusions and recommendations from the feed trials.

The feed trials discussed in this chapter were carried out over a period of more than three years. Three main topics were addressed in the trials:

(i) The comparative growth performance of different fish species.

(ii) The effect of changes in the major components of feed formulations on fish performance.

(iii) The effect of changes in the supply of micronutrients, particularly vitamins, on fish performance.

(i) The comparative growth performance of different fish species.

Only one trial, feed trial 2, attempted to compare the growth of different fish species. More work was carried out in the production tanks and has been described in Chapter 3. Feed trial 2 was carried out in rectangular, non self cleaning tanks. *O. macrochir, O. niloticus* and *O. aureus* showed poor growth associated with breeding activity. *O. andersonii* grew slightly better and only carp showed reasonable growth. If these results are compared to the cumulative results from production tanks shown in Table 6 (p.40), it is immediately apparent how poor the growth of all the fish in this trial was compared to those grown in production tanks.

There were probably two main reasons for depressed growth of fish in the rectangular trial tanks:

1. Poor water distribution led to an accumulation of uneaten food and faeces in the corners of the tanks, that is, the tanks were not self cleaning. Although this was cleaned out manually at least once a day, this may have led to localised deoxygenation

or a build up of metabolic products leading to stress in the fish , making them less likely to feed or grow well. Wheaton(1977) lists among the most important qualities for an ideal culture tank, that it must be self cleaning and states that water circulation in rectangular tanks is often characterised by "dead" areas and short circuiting. It is probably this factor which explains the large difference in growth rates observed between carp grown in the rectangular trial tanks and the self cleaning production tanks.

2. In addition to the fact that the tanks were not self cleaning, growth of tilapias in the rectangular trial tanks was clearly affected by reproductive activity of the fish. The rectangular design and uneven water distribution encouraged reproductive behaviour of tilapias by allowing males to establish territories and by giving females a substrate on which to safely deposit and retrieve eggs without them being swept to the tank outlet. Most species of tilapia are very adaptable with regard to the onset of breeding. Once they have reached a particular size, if they get the opportunity, they will breed and once breeding commences, growth is restricted (Balarin and Haller, 1982). This means that in feed trial 2, although it was designed to compare fish growth between species, it really only compared the size at which these species would mature precociously in this tank system. In contrast to the results of this feed trial, over the period of the study, successful reproduction of tilapias was never observed in the self cleaning, D-ended production tanks. This is probably because high stocking densities and uniform water flow prevented the establishment of territories by males, and any eggs deposited on the tank bottom were swept to the tank outlet before they could be retrieved by females.

Since it is clear that tank design can have a very significant effect on the growth of fish, and particularly of tilapias, it is surprising that a wide range of holding facilities are used for experimental work on the intensive culture of tilapias. These range from cages suspended in tanks or ponds (Viola and Arieli, 1983), to self cleaning tank systems (Jackson *et al* 1982) and non self cleaning tanks or aquaria. Many workers fail to mention whether the systems used were self cleaning (Santiago and Lovell, 1988; Shiau *et al* 1987; Ofujekwu and Ejike, 1984; Teshima *et al* 1986). Although most of these experiments used very small fish which would not be capable of reproductive behaviour, use of non self cleaning tank systems could clearly introduce a growth depressing factor which may obscure the main aims of the experiment.

Of the tilapia species used at Nakambala, *O. niloticus* is the most widely used for aquaculture (Pullin and Capili, 1987). The main reasons for this are the ease of obtaining good stock, easy propogation and good growth in intensive and extensive conditions. Pauly *et al* (1987) analysed growth data for a number of tilapia species in wild stocks and in aquaculture. This suggested that the ranking for species used at Nakambala should be *O. niloticus*, *O. aureus*, *O. andersonii* and *O. macrochir* in decreasing order of growth index. This fits precisely with the data summarised in Table 6 (p.39) on the growth rates of these species in production tanks.

Although the growth rates shown by carp in production tanks indicated that they could achieve faster growth than any of the tilapia species, their incorporation in large numbers into the production system would have depended on the propogation of large numbers of fingerlings. It was felt that the extra effort required was not justified as the market for carp was uncertain.

(ii) The effect of changes in the major components of feed formulations on fish performance.

Eight of the feed trials used feeds in which one or more of the major constituents were changed. Feed trials 1, 3, 5, 6 and 7 were carried out in the rectangular, non-selfcleaning trial tanks. For reasons which were discussed above, fish performance in these tanks was generally very poor. Similar fish fed similar feeds in self cleaning production tanks, grew faster and converted food more efficiently than those in the trial tanks, even when all male tilapias were stocked as in trials 5, 6 and 7. This supported the conclusion that poor tank design was a major interfering factor in these trials, with none yielding statistically significant differences in growth or food conversion between treatments.

Three trials were carried out in improved experimental tank systems. Good growth and food conversion was shown in all three.

Feed trials 15 and 17 investigated the use of different protein sources in the feeds, comparing kapenta(dried fish) and blood meal as animal protein sources and the replacement of animal protein with plant protein from luceme, leucaena and oilseeds. The main practical difference between plant and animal protein sources is price. If the approximate cost per kilogramme of protein is calculated, for some of the main feed ingredients(based on 1986 prices - Table 10), kapenta protein cost K5/kg, blood meal protein cost K4.20/kg, soyabean protein cost K2.80/kg, sunflower oilcake protein cost K1.20/kg and wheatings protein cost K1.10/kg. Clearly there was a strong economic incentive to substitute animal protein with plant protein. Also plant protein sources were generally more easily available than animal protein in Zambia. On the other hand, animal protein sources usually contain high levels of easily digestible protein

often with a good balance of amino acids, so inclusion of relatively small quantities can improve the protein level and quality significantly(New, 1987).

It would appear from the results of trials 15 and 17 that in some cases, plant protein can effectively replace animal protein with no discernable effect on fish performance. Interestingly there were marked differences between animal protein sources. Blood meal was shown to be an inferior feed ingredient when compared to kapenta.

Many studies report that animal based feedstuffs are a better source of protein for tilapias than plant based feedstuffs, however most conclude that plant protein can be used in limited quantities to replace animal protein(Jackson *et al*, 1982; Ofujekwu and Ejike, 1984; Appler, 1985; Hanley, 1987; Shiau *et al*, 1987). The usual reasons given for decreased growth rates at higher inclusion rates of plant protein are:

1. Lower digestibility of plant protein.
2. Limiting essential amino acid levels in plant proteins.
3. The presence of toxic factors in most plant protein sources.

Recent studies in Israel have highlighted another important factor which may have been overlooked in previous studies. In attempting to produce an animal protein free feed for tilapias they have found the availability of phosphorus in the feeds to be very important. Phosphorus in fish meal was found to be highly available whereas plant phosphorus was not. Supplementation of a plant based feed with dicalcium phosphate resulted in growth rates comparable to those achieved using conventional fish meal based feeds. If dicalcium phosphate was left out of the plant based feed, growth was reduced by 20%(Viola *et al*, 1986(a); Viola *et al*, 1986(b); Viola *et al*, 1988(a); Viola *et al*, 1988(b). This illustrates the dangers inherent in changing feed formulations in practical feeds Whilst the main intention in a trial may be to compare the effect of supplying protein from a plant source with that from an animal source, other factors

are also changed, in this case, the availability of phosphorous, and this can outweigh the anticipated effects such as those resulting from changes in the amino acid profile.

This work also shows that animal protein free feeds for tilapias in intensive culture is a real possibility, with consequent savings in feed costs. This suggests that tilapias are much less affected by changes in the amino acid profile of feeds than has previously been thought.

Feed trial 16 investigated the use of a wide range of feed base materials. The conclusion was that there was no significant difference in fish performance between the treatments. This is remarkable given the large differences in the appearance and texture of the feeds. and once again illustrates the versatility of tilapia feeding habits.

(iii) The effect of changes in the supply of micronutrients, particularly vitamins, on fish performance.

Of the seventeen trials, twelve were either wholly or partially designed to determine whether vitamin supplementation of tilapia feeds was necessary. Six of these were carried out in the non self cleaning test tanks, where fish performance was adversely affected by the tank design and results were inconclusive. The other six were carried out in self-cleaning tanks. where fish growth was satisfactory. The results have been fully discussed at the end of Feed Trial 14. The main conclusion was that there was no clear evidence to show that vitamin supplementation of the feeds was necessary. Fish fed diets without vitamin supplements, performed as well as those fed supplemented diets.

This conclusion contradicts the recommendations of many workers who have demonstrated hypovitaminosis in tilapias (Jauncey *et al*, 1985; Soliman *et al* 1986; Soliman *et al* 1987) and with reviews on the dietary requirements of tilapias (Jauncey and Ross, 1982; N.R.C., 1983), however it is in agreement with results presented by Viola and Zohar(1986) who demonstrated that a vitamin supplement was not necessary for tilapia feeds in Israel. This anomalous situation suggests that tilapias can behave differently in different situations. In laboratory studies, clear vitamin deficiencies have been demonstrated, whereas in practical situations, vitamin deficiency is not easily demonstrated.

As discussed at the end of feed trial 14, the supplies of vitamins available to tilapias in intensive culture are:

1. In the feed(natural or artificial).
2. From storage in the fish tissues.
3. Produced by the fish.
4. Produced by the intestinal microflora.

If a vitamin deficient food is used, no signs of deficiency are detected and it is assumed that an insignificant quantity of vitamins are harvested from the water, then vitamins must be supplied from storage or metabolism by the fish or from the gut microflora. The fish used in experiments at Nakambala were bred from stock imported from Stirling University, probably the same stock as was used by Jauncey and co-workers at Stirling in which vitamin C deficiency was clearly demonstrated. It would be surprising if these fish acquired the ability to synthesise vitamins in the few generations since importation so production in the fish tissues seems unlikely. In general the experiments carried out at Nakambala were of longer duration than those used to show vitamin C deficiency at Stirling so storage of vitamins seems an unlikely

explanation These points suggest that in a farm situation, a significant contribution may be made to the supply of vitamins in tilapias by *microbial action in the fish gut.* It could be that the gut microflora are more active in farm fish than in laboratory reared fish, hence the differing results between researchers. Although feed trial 14 attempted to address this, the results were inconclusive. Much more work needs to be carried out to determine whether tilapia gut microflora make a significant contribution to the fishes nutrition.

If it is shown that this is an important factor, this may also explain the versatility of tilapias with regard to other nutrients such as proteins. Recent Israeli research has demonstrated that not only is a vitamin supplement unnecessary, neither are amino acid supplements in an animal protein free feed(Viola, pers. comm.). If tilapias possess an active gut microflora, capable of supplying vitamins and essential amino acids, it may be simplistic to consider them as monogastric animals. It would be more appropriate to consider them as possessing digestive similarities with ruminants, which would require a fundementally different nutritional approach

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS.

8.1. Project implementation.

The fish farm was set up as a commercial enterprise within the sugar estate. As such it was expected to make a profit and save the Zambia Sugar Company money which would have been spent on buying food for the workers. Financially it performed very badly. If it had been run as a commercial venture separate from the sugar estate, it would undoubtedly have been closed down in the first years of operation. The first harvest of fish was two years behind schedule and the quantities harvested were much lower than anticipated.

Initial stocking with *O. macrochir* was disastrous as they did not grow at anywhere near the expected rates. *O andersonii* and *O. aureus* showed some promise, but it was only when sufficient *O. niloticus* juveniles were available for ongrowing that the production target of 50 tonnes per annum was achieved, four years after the project started. This underlines the importance of having a complete technical package available before embarking on a commercial operation. The most important part of this package proved to be fish which would perform well in the highly intensive conditions. needed to maximise production from the tanks. In hindsight it was nlave to think that any of the indigenous tilapias could be used. More effort should have been put into ensuring that sufficient fingerlings of a proven species were available at the start of operation.

Identification of suitable feed ingredients and feed processing methods also took some time, although the pressure on feed production was made easier by the relatively small quantities used in the early years of the project.

In essence the first two years operation was mainly research and perhaps it would have been more sensible to have approached it as such from the start. This would have allowed for a phased development, with the initial efforts concentrated on research to establish whether the local species of fish were suitable for intensive culture, to develop suitable feedstuffs and to establish a breeding programme for the preferred species. Once these points had been addressed, the main capital expenditure on rearing facilities would have proceeded.

This phased approach would also have allowed for greater flexibility. In any project with a significant research component, thoughts and priorities often change as a result of the research. This was particularly true for the algae culture programme. All the money allocated for capital expenditure was used up at the start of the programme. It would have been better to restrict initial spending to the bare essentials, leaving a reserve for developing ideas generated after the start of the project. If there had been funds to develop a carbon dioxide supplementation system for the algae ponds, the project could well have turned from a failure, to one which suceeded in supplying significant quantities of raw materials for tilapia feeds.

The phased approach is not, however, attractive to commercial companies such as the Zambia Sugar Company. Allocations of foreign exchange must be made well in advance and used promptly once allocated, also commercial companies often do not want to get involved in research.

8.2 Feeds.

It was clear that the farm was able to produce feeds which were perfectly adequate for the growth of tilapias. The feed formulations used on the farm changed over the course of the study not only as a result of experience gained from fish performance in production and research tanks, but also in response to changes in the availability of raw materials. This became particularly important as the quantities of feeds being produced increased (Table 13, p.81). This meant that only those ingredients which were reasonably easily available could be used in the feeds. The use of some materials such as fish silage and raw blood, which were investigated early in the study, had to be discontinued as the quantities available were too small, the quality was too variable and handling was too difficult. Table 47 summarises the conclusions on the usefulness of the feed ingredients used during the study.

At the end of the study, the main feed ingredients used were: kapenta, blood meal, fullfat soyabeans, sunflower oilcake, wheatings, lucerne and leucaena (see Table 11 p.78). The main problem was that interruptions in the supply of some of the ingredients sometimes led to them being replaced by others. In emergencies kapenta was used to replace blood meal and blood meal to replace kapenta. Soyabeans and sunflower oilcake were also used interchangeably as were leucaena and lucerne, however feed formulations returned to normal as soon as possible. The results of Feed Trial 17 showed that such substitutions can have an adverse effect on fish growth, in that case by substituting kapenta with blood meal, however substitution kept feed production going and in many situations was all that could be done at the time.

Table 47. Conclusions on the use and usefulness of various feed ingredients.

Ingredient	Feed value	Convenience	Supply	Price	Comments
Animal Products					
Fish silage	+	+	+	+++	Supply too erratic
Kapenta	+++	++	++	+++	Preferred animal ingredient.
Rawblood	+	+	+	+	Supply too erratic
Blood meal	++	++	++	+++	Useful but expensive
Carcasemeal	++	++	++	+++	Quality often suspect
Hyd.Feather meal	++	+	+	+	Needs reliable supply of poultry feathers.
Plant Products					
Soyabeans	+++	++	+++	++	Very useful ingredient
Cottonseed	+	+	++	++	Processing too difficult
Sunflower oilcake	++	+++	++	++	Preprocessed cake useful
Lucerne	++	+	own	+	{Useful although long time
Leucaena	++	+	own	+	{required to establish plots.
Wheatings	+++	+++	++	+	Very useful
Maize	++	++	++	+++	Too valuable as human food
Bagasse/mollasses	+	+	+++	+	Useful in emergencies
Algae	+	++	+	+++	Quality and quantity too low
Yeast	++	++	+	+++	Supply too erratic

Key: + Low (Feed value, convenience, supply or price)

++ Medium (Feed value, convenience, supply or price)

+++ High (Feed value, convenience, supply or price)

Much of the feed research concentrated on the supply of vitamins in the feeds because this was the only class of nutrients which it was impossible to supply at anything like the recommended levels. That the feed trials indicated a vitamin supplement was not essential, shows that there is a great deal to be learnt about tilapia nutrition. Until further research is able to prove this point conclusively and explain why it is so, feed manufacturers and *nutritionists* will continue to be conservative in their approach, recommending that vitamin supplements are included in *feeds for tilapias in* intensive culture, with the resultant conclusion that the intensive culture of tilapias is impossible in those countries where a vitamin supplement cannot be supplied.

sraeli research (Viola, pers.comm.) has shown that not only are vitamin supplements not essential in practical feeds for intensive tilapia culture, but neither are amino acid supplements or oil supplements. The only supplement they found essential in an animal protein free feed was available phosphorous. This would indicate that the current recommendations are far too stringent. If the Israeli research is correct, the nutritional requirements of tilapias would seem to be remarkably easy to meet, making them ideal for intensive culture in developing countries.

Another conclusion which resulted from the feed trials was the importance of the behavioural component in fish growth. In most of the trials, the object was to ascertain differences in growth response due to differences in the nutritional composition of the feeds, but often these were masked by differences in growth due to the behavioural responses of the fish to their environment and to eachother. It would be advantageous for tilapia culture if the influence of fish behaviour could be reduced,

for example by altering their genetics to produce later maturing fish, but until this can be achieved it must be recognised that the culture system adopted has a large part to play in influencing fish growth. Of the systems in use at present, self cleaning round or D-ended tanks, or cages, would seem to be best for intensive culture, whereas monosex culture may be best for more extensive systems.

Future research which should be carried out on feeds is:

1. Establish the source of vitamins in unsupplemented tilapia feeds. If tilapias derive a significant nutritional contribution from gut microflora, a different approach may be required in feeding.

2. Continue to reduce the levels of expensive ingredients such as animal byproducts in the feeds and replace with cheaper and more easily available ingredients.

3. Investigate the digestibility of nutrients in diferent feeds. Although digestion studies are hampered by the aquatic environment, they are crucial to a complete understanding of tilapia nutrition.

4. Continue investigations on the most appropriate feed processing methods.

8.3. Is intensive culture appropriate in Zambia?

The Nakambala Tilapia Farm is one of the most intensive in the World. It would seem at first analysis to be inappropriate to operate in a developing country because of the complexity of engineering used in its construction and operation. A useful comparison is with the fish farm at Kafue Fisheries near Kafue, Zambia, which used a much lower technology approach. They operated a farm which used effluent from piggeries to fertilise fish ponds.

Nakambala Tilapia Farm had two major raw material inputs, water and feed ingredients, both of which were reasonably easy to control. Kafue Fisheries required pig feeds, water and regular supplies of piglets. They also had to integrate the growth cycle of the pigs with the fish. The supply of pig feeds depended on the feed milling companies which, given the state of the economy, meant that at times they were unavailable. The supply of piglets was also outwith the control of the farm.

At Nakambala, feeding was based on rations calculated from the results of regular sample weighings in the tanks. At Kafue Fisheries, feeding was more an art than a science, involving the culture of algae on the piggery effluent to feed the fish. Control of feeding rates and growth is difficult in such a system. This lack of control also made marketing of the produce difficult, as it was difficult to predict when a particular pond would be ready for harvest.

Although Kafue Fisheries was technologically more simple, its operation and management would be considerably more difficult than the intensive system utilised at Nakambala, also the lack of control over some of the key inputs make its operation much more vulnerable to the fluctuating fortunes of the Zambian economy.

The conclusion must be that the intensive system used at Nakambala was as appropriate as any other system in use in Zambia at the time of completion of this study.

REFERENCES

Abel H.J., Becker K., Meske C.H.R. and Friedrich W., 1984. Possibilities of using heat treated full-fat soybeans in Carp feeding. Aquaculture, 42: 97 - 108.

Allison R., Smitherman R.O. and Cabrero J., 1976. Effects of high density culture on reproduction and yield of *Tilapia aurea* F.A.O. Tech. Conf. on Aquaculture, Kyoto, Japan. AQ/Conf./76/E.47. 3pp.

Appler H.N. and Jauncey K., 1983. The utilisation of a filamentous green alga (*Cladophora glomerata* (L) Kutzin) as a protein source in pelleted feeds for *Sarotherodon* (tilapia) *niloticus* fingerlings. Aquaculture, 30: 21 - 30.

Appler H.N., 1985. Evaluation of *Hydrodiction reticulatum* as a protein source in feeds for *Oreochromis niloticus* and *Tilapia zillii*. Journal of Fish Biology, 27(3): 327 - 334.

Avault J.W. and Shell E.W., 1967. Preliminary studies with the hybrid tilapia *Tilapia nilotica* x *T.mossambica* F.A.O. Fisheries Reports 44: 237 - 242.

Balarin J.D. and Haller R.D., 1982. The intensive cultivation of tilapia in tanks, raceways and cages. In: Recent Advances in Aquaculture, Vol.1. J.F.Muir and R.J. Roberts (eds.). Croom Helm, London.

Balarin J.D. and Hatton J.D., 1979. Tilapia - A guide to their biology and culture in Africa. Institute of Aquaculture, University of Stirling. 174pp.

Barash H, 1984. Growth rates of young tilapia fingerlings fed on commercial eel and trout diets. Bamidgeh, 36(3): 70 - 79.

Barlow S.M, 1976. Fishmeal manufacture in the Tropics. In: Proceedings of the Conference on the handling, processing and marketing of tropical fish: 223 - 230. Tropical Products Institute, London.

Benemann J.R, Weissman J.C, Koopman B.L and Oswald W.J, 1977. Energy production by microbial photosynthesis. Nature, 268: 19 - 23.

Benemann J.R, Weissman J.C and Oswald W.J, 1979. Algal biomass. In: Economic Microbiology 4(ed. by A.H. Rose), pp. 177 - 208. Academic Press, London.

Berrios-Hernandez J.M and Snow J.R, 1983. Comparison of methods for reducing fry losses to cannibalism in tilapia production. Progressive Fish Culturalist, 45(2): 116 - 118.

Beveridge M.C.M, 1987. Cage Aquaculture. Fishing News Books Ltd, Surrey, England. 352pp.

Black W.B, 1981. Proposal for commercial fish production. Tate and Lyle Technical Services report. 53pp.

Bratby J, 1980. Coagulation and flocculation. Uplands Press Ltd, Croydon.

Coche A.G, 1977. Preliminary results of cage rearing *Tilapia nilotica* in Lake Kossou, Ivory Coast. Aquaculture, 10: 109 - 140.

Cowey C.B. and Sargent J.R, 1977. Lipid nutrition in fish. Comp. Biochem. Physiol. 57B: 269 - 273.

Cruz E.M. and Laudencia I.L, 1978. Screening of feedstuffs as ingredients in rations of Nile "Tilapia". Kalikasan, Phillip.J.Biol, 7(2): 159 - 163.

Delcambe-Fontaine P, 1979. Report on feeding experiments at Liege. Tate and Lyle Technical Services report. 6pp.

De Pauw N, De Leeneer L, Laureys P, Morales J. and Reartes J, 1980. Cultures d'algues et d'invertebres sur dechets agricoles. Communication presentee au "Colloque sur la pisciculture d'Etang". 11 - 13 March 1980. Arbonne la Foret, 77630 Barbizan, France.

Dickson M.W, 1981. Assessment of six different feeds for Sarotherodon spp. in Kenya. M.Sc. Thesis, Institute of Aquaculture, University of Stirling. 70pp.

Disney J.G, Tatterson I.N. and Olley J, 1976. Recent developments in fish silage. Proceedings of the conference on the handling, processing and marketing of tropical fish. London 5 - 9 July 1976. 231 - 240. Tropical Products Institute, London.

Duncan D.B, 1955. Multiple range and multiple F - test. Biometrics, 11: 1 - 42.

Edwards P. and Sinchumpasak O.A, 1981. The harvest of microalgae from the effluent of a sewage fed high rate stabilisation pond by Tilapia nilotica. Part 1: Description of the system and the study of the high rate algal pond. Aquaculture, 23: 83 - 105.

Edwards P, Sinchumpasak O.A. and Tabucanon M, 1981. The harvest of microalgae from the effluent of a sewage fed high rate stabilisation pond by Tilapia nilotica. Part 2: Studies of the fish ponds. Aquaculture, 23: 107 - 147.

Edwards P, Sinchumpasak O.A, Labhsetwar V.K. and Tabucanon M, 1981. The harvest of microalgae from the effluent of a sewage fed high rate stabilisation pond by Tilapia nilotica. Part 3: Maize cultivation experiment, bacteriological studies and economic assessment. Aquaculture, 23: 149 - 170.

Gohl B, 1981. Tropical feeds - feed information summaries and nutritive values. 529pp. F.A.O. Animal production and Health Series No. 12.

Goldman J.C, 1979. Outdoor algal mass cultures. I. Applications. Water Research, 13: 1 - 19.

Goldman J.C, Azov Y, Riley C.B. and Dennet M.R, 1982. The effect of pH in intensive microalgal cultures. I. Biomass regulation. Journal of Experimental Marine Biology and Ecology, 57: 1 -13.

Guerrero R.D, 1975. Use of androgens for the production of all male *Tilapia aurea* (Steindachner). Trans. Am. Fish. Soc. 104(2): 342 - 8.

Halver J.E, 1979. Vitamin requirements of finfish. In: Proc. World Symp. of Finfish Nutrition and Fishfeed Tecnology, Hamburg 1978. Halver J.E. and Tiews K. (eds.) Heeneman, Verlag, Berlin. Vol 1. p. 45 - 58.

Hanley F, 1987. The digestibility of foodstuffs and the effects of feeding selectivity on digestibility determinations in tilapia, *Oreochromis niloticus* (L). Aquaculture 66(2): 163 - 179.

Hepher B, Sandbank E. and Shelef G, 1978. Alternative protein sources for warmwater fish diets. EIFAC/78/Symp: R/112. pp. 1 - 29.

Hilton J.W. and Slinger S.J, 1983. Effect of wheat bran replacement of wheat middlings in extrusion processed (floating) diets on the growth of juvenile Rainbow Trout (*Salmo gairdneri*). Aquaculture, 35: 201 - 210.

Horwitz W, 1980. Official methods of analysis of the association of official analytical chemists. Publication by A.O.A.C. Washington.

Huet M, 1972. Textbook of fish culture: Breeding and cultivation of fish. Fishing News Books Ltd, Surrey, England. 438pp.

Jackson A.J. and Capper B.S, 1982. Investigations into the requirements of the tilapia *Sarotherodon mossambicus* for dietary Methionine, Lysine and Arginine in semi-synthetic Diets. Aquaculture, 29: 289 - 297.

Jackson A.J, Capper B.S. and Matty A.J, 1982. Evaluation of some plant proteins in complete diets for the tilapia, *Sarotherodon mossambicus* Aquaculture, 27: 97 - 109.

James M.A., Iyer K.M. and Nair M.R, 1976. Comparative study of fish ensilage prepared by microbial fermentation and formic acid ensilage. Proceedings of the conference on the handling, processing and marketing of tropical fish. London 5 - 9 July, 1976. 273 - 276. Tropical Products Institute, London.

Jauncey K, 1982. The effects of varying dietary protein level on the growth, food conversion, protein utilization and body composition of juvenile tilapias(*Sarotherodon mossambicus*). Aquaculture, 27: 43 - 54.

Jauncey K, 1984. Report on visit to Zambia, November 2 - 17, 1983. Institute of Aquaculture, University of Stirling. 33pp.

Jauncey K. and Ross B, 1982. A guide to tilapia feeds and feeding. Institute of Aquaculture, University of Stirling, Stirling.

Jauncey K. and Ross B, (In Press). A guide to tilapia feeds and feeding. Institute of Aquaculture, University of Stirling, Stirling.

Jauncey K, Soliman A.K. and Roberts R.J, 1985. Ascorbic acid requirements in relation to wound healing in the cultured tilapia *Oreochromis niloticus* (Trewavas). Aquaculture and Fisheries Management, 16: 139 - 149.

Jauncey K, Tacon A.G.J, and Jackson A.J, 1983. The quantitative essential amino acid requirements of *Oreochromis(Sarotherodon) mossambicus* In: International Symposium on Tilapia in Aquaculture(1st Proceedings, Nazereth, Israel)(Fishelson L. and Yaron Z., eds.). pp.328 - 337, Tel Aviv University, Israel.

Jones B.D., 1974. Aflatoxin in feeding stuffs - its incidence, significance and control. Proceedings of the Conference on Animal Feeds of Tropical and Sub-tropical Origin. London 1 - 5 April 1974. Tropical Products Institute, London.

Jorgensen J., 1953. Cultivation of complexes of algae with other freshwater organisms in the tropics. In: Algal Culture from Laboratory to Pilot Plant (ed. by J.S. Burlew) pp. 190 - 196. Publication No. 600, Carnegie Institute, Washington.

Kohler C.C. and Pagan-Font F.A., 1978. Evaluations of rum distillation wastes, pharmaceutical wastes and chicken feed for rearing *Tilapia aurea* in Peurto Rico. Aquaculture 14: 339 - 347.

Lall S.P., 1978. Minerals in finfish nutrition. Proceedings of World Symposium on Finfish Nutrition and Fishfeed Technology, Hamburg 20 - 23 June 1978.

Leary D.F. and Lovell R.T., 1975. Value of fiber in production-type diets for channel catfish. Trans. Am. Fish. Soc. 104: 328 - 332.

Lovell R.T. and Limsuwan T., 1982. Intestinal synthesis and dietary nonessentiality of vitamin B_{12} for *Tilapia nilotica*. Transactions of the American Fisheries Society, 111: 485 - 490.

Maar A., Mortimer M.A.E. and Van der Lingen, 1966. Fish culture in Central East Africa. F.A.O. Fisheries Series No. 20, F.A.O., Rome. 158pp.

MacBain R., 1966. Pelleting, formulation, conditioning, operating techniques. Text of presentation to AFMA regional feed production schools. 23pp.

Macintosh D.J. and Sampson D.R.T., 1985. Tilapia culture: hatchery methods for *Oreochromis mossambicus* and *O. niloticus* with special reference to all-male fry production. Institute of Aquaculture, University of Stirling. 154pp.

McDonald P., Edwards R.A., and Greenhaugh J.F.D., 1981. Animal Nutrition, 3rd edition. Longman, London.

Melarde C. and Phillipart J.C., 1980. Pisciculture intensive de *Sarotherodon niloticus* dans les effluents thermique d'une centrale de Belgique. Schr. der Bundesforschungstalt. Fisch., 16/17: 637 - 685.

Msiska O.V., 1983. Yield of *Sarotherodon mossambicus* using inorganic fertilisers and rice bran in southern Malawi. Aquaculture 32: 201 - 205.

National Research Council, 1983. Nutrient Requirements of Warmwater Fishes and Shellfishes. Committee on Animal Nutrition, National Academy Press, Washington DC.

New M, 1987. Feed and Feeding of Fish and Shrimp. F.A.O. ref: ADCP/REP/87/26. 275pp. F.A.O., Rome.

Nose T. and Arai S., 1976. Recent Advances in studies on mineral nutrition of fish in Japan. F.A.O. Technical Conference on Aquaculture, Kyoto, Japan.(26 May - 2 June 1976) pp. 10.

Nurse and Thorp, 1981. Leucaena. Govt. of the Republic of Zambia leaflet. Mount Makulu Research Station, Chilanga, Zambia.

Ofujekwu P.C. and Ejike C, 1984. Growth response and feed utilisation in the tropical cichlid *Oreochromis niloticus* (Linn.) fed cottonseed based artificial diets. Aquaculture 42: 27 - 36.

Ogino C, 1980. Requirement of carp and rainbow trout for essential amino acids. Bull. Jap. Soc. Sci. Fish., 46: 171 - 174.

Oswald W.J, 1969. Current status of microalgae from wastes. Chemical Engineering Progress Symposium Series 65: 89 - 92.

Otubisin S.O, 1987. Effects of different levels of blood meal in pelleted feeds on tilapia, *Oreochromis niloticus* production in floating bamboo net-cages. Aquaculture, 65: 263 - 266.

Payne J.D, 1978. Improving quality of pellet feeds. Milling, Feed and Fertiliser, May 1978.

Pruginin Y, 1975. Species competition and stock densities in aquaculture in Africa. In: Symposium on Aquaculture in Africa. Ghana, 30 September - 2 October 1975. F.A.O, Rome. 5pp.

Raa J. and Gildberg, 1982. Fish silage: a review. C.R.C. Critical Reviews in Food Science and Nutrition, 16: 383 - 419.

Robinson E.H, Rawles S.D, Oldenburg P.W. and Stickney R.R, 1984. Effects of feeding glandless or glanded cottonseed products and gossypol to *Tilapia aurea* Aquaculture, 38: 145 - 154.

Robinson E.H, Rawles S.D, Yette H.E and Greene L.W, 1984. An estimate of the dietary calcium requirement of fingerling *Tilapia aurea* reared in calcium-free water. Aquaculture, 41: 389 - 393.

Ross B, 1982. The Protein Requirements of *Sarotherodon massambicus*. University of Stirling.

Ruwet J.C, Voss J, Hanon L and Micha J.C, 1975. Biologie et elevage des tilapia. In: Symposium on Aquaculture in Africa. Ghana, 30 September - 2 October 1975. F.A.O, Rome.

Santiago C.B, Aldaba M.B, Abuan E.F. and Laron M.A, 1985. The effects of artificial diets on fry production and growth of *Oreochromis niloticus* breeders. Aquaculture, 47: 193 - 203.

Santiago C.B. and Lovell R.T, 1988. Amino acid requirements for growth of Nile Tilapia. Journal of Nutrition, 118: 1540 - 1546.

Sarig S. and Arieli Y, 1980. Growth capacity of tilapia in intensive culture. Bamidgeh 32(3): 57 - 65.

Shelef G, Oswald W.J. and Golueke C.G, 1969. The continuous culture of algal biomass on wastes. In: Continous Cultivation of Micro-organisms (ed. by I. Malek *et al*): 601 - 629. Academic Press, London.

Shewan R, 1976. The bacteriology of fresh and spoiling fish and the biochemical changes induced by bacterial action. Proceedings of the conference on the handling, processing and marketing of tropical fish. London 5 - 9 July, 1976. 51 - 66. Tropical Products Institute, London.

Shiau S.Y, Chuang J.L and Sun C.L, 1987. Inclusion of soyabean meal in tilapia(*Oreochromis niloticus x O. aureus*) diets at two protein levels. Aquaculture, 65: 251 - 261.

Slinger S.J, Razzaque A and Cho C.Y, 1979. Effect of feed processing and leaching on the losses of certain vitamins in fish diets. Proceedings of the World Symposium on Finfish Nutrition and Fishfeed Technology, 2: 425 - 434.

Soeder C.J, 1980. Massive cultivation of microalgae: results and prospects. Hydrobiologia, 72: 197 - 209.

Soliman A.K, Jauncey K and Roberts R.J, 1985. Qualitative and quantitative identification of L-gulonolactone oxidase activity in some teleosts. Aquaculture and Fisheries Management, 16: 249 - 256.

Soliman A.K, Jauncey K and Roberts R.J, 1986. The effect of varying forms of dietary ascorbic acid on the nutrition of juvenile tilapias (*Oreochromis niloticus*). Aquaculture, 52: 1 - 10.

Soliman A.K, Jauncey K and Roberts R.J, 1986. The effect of dietary ascorbic acid supplementation on hatchability, survival rate and fry performance in *Oreochromis mossambicus*(Peters). Aquaculture, 59: 197 - 208.

Soliman A.K, Jauncey K and Roberts R.J, 1987. Stability of L-ascorbic acid (vitamin C) and its forms in fish feeds during processing, storage and leaching. Aquaculture, 60: 73 - 83.

Stickney R.R, 1979. Principles of Warmwater Aquaculture. Wiley-Interscience Publications, New York.

Stickney R.R. and Wurtz W.A., 1986. Growth response of blue tilapias to selected levels of dietary menhaden and catfish oils. The Progressive Fish Culturist, 48: 107 - 109.

Subasinge S. and Sommerville C., 1985. Disinfection of Orechromis mossambicus (Peters) eggs against commonly occurring potentially pathogenic bacteria and fungi under artificial hatchery conditions. Aquaculture and Fisheries Management 16: 121 - 127.

Tacon A.G.J. and De Silva S.S., 1983. Mineral composition of some commercial fish feeds available in Europe. Aquaculture, 31: 11 - 20.

Tacon A.G.J., Haaster J.V., Featherstone P.B., Kerr K. and Jackson A.J., 1983. Studies on the utilisation of full fat soybean and solvent extracted soybean meal in a complete diet for Rainbow Trout. Bull. Jap. Soc. of Sci. Fish., 49(9) 1437 - 1443.

Tacon A.G.J., Jauncey K., Falaye A., Pantha M., MacGowan I. and Stafford E.A., 1983. The use of meat and bone meal, hydrolysed feather meal and soybean meal in practical fry and fingerling diets for *Oreochromis niloticus*. In: International Symposium on Tilapia in Aquaculture(1st Proceedings, Nazereth, Israel)(Fishelson L. and Yaron Z., eds.). pp.356 - 365, Tel Aviv University, Israel.

Teshima S., Kanazawa A. and Uchiyama Y., 1985. Optimum protein levels in casein-gelatin diets for *Tilapia nilotica* fingerlings. Mem. Fac. Fish., Kagoshima Univ., 34. No.1: 45 - 52.

Teshima S, Kanazawa A. and Uchiyama Y, 1986. Effect of several protein sources and other factors on the growth of *Tilapia nilotica*. Bulletin of the Japanese Society of Scientific Fisheries 52(3): 525 - 530.

Viola S. and Arieli Y, 1983(a). Nutrition studies with tilapia(Sarotherodon). 1. Replacement of fishmeal by soybean meal in feeds for intensive tilapia culture. Bamidgeh, 35(1): 9 - 17.

Viola S. and Arieli Y, 1983(b). Evaluation of different grains as basic ingredients in complete feeds for carp and tilapia in intensive culture. Bamidgeh, 35(2): 38 - 43.

Viola S, Arieli Y. and Zohar G, 1986(b). Phosphorus levels and sources for complete feeds for carp and tilapia.(Text in Hebrew) Fish and Fishbreeding in Israel. 19(3): 25 - 38.

Viola S, Arieli Y. and Zohar G, 1988(a). Animal protein free feeds for hybrid tilapia in intensive culture.(Text in Hebrew) Fish and Fishbreeding in Israel. 21(1): 19 - 24.

Viola S, Arieli Y. and Zohar G, 1988(b). Animal protein free feeds for hybrid tilapia (*Oreochromis niloticus* x *O. aureus*) in intensive culture. Aquaculture. 75(1-2):115 - 125.

Viola S, Gur N. and Zohar G, 1985. Effects of pelleting temperature, binders and basic grains on water-stability of pellets and on growth of tilapia. Bamidgeh, 37(1): 19 - 26.

Viola S., Mokady S. and Arieli Y., 1983. Effects of soybean processing methods on the growth of carp(*Cyprinus carpi*). Aquaculture, 32: 27 - 38.

Viola S. and Zohar G., 1984. Nutrition studies with market size hybrids of tilapia(*Oreochromis*) in intensive culture. Bamidgeh, 36(1): 3 - 15.

Viola S. and Zohar G., 1986. Inessentiality of vitamin supplements to commercial tilapia feeds for intensive culture in Israel. (Text in Hebrew) Fisheries and Fishbreeding in Israel, 18: 31 - 36.

Viola S., Zohar G. and Arieli Y, 1986(a). Phosphorus requirements and its availability from different sources for intensive pond culture species in Israel. Part 1. Tilapia. Bamidgeh, 38(1): 3 - 12.

Watanabe T., Takeuchi T., Murakami A. and Ogino C., 1980. The availability to *Tilapia nilotica* of phosphorous in white fish meal. Bulletin of the Japanese Society of Scientific Fisheries, 46(7): 897 - 899.

Wheaton F.W., 1977. Aquaculture Engineering. Wiley-Interscience, New York. 308pp.

White A., Handler P. and Smith E.L., 1964. Principles of Biochemistry. McGraw - Hill, New York. 1106pp.

Wong M.H. and Lay C.G., 1980. The comparison of soya bean wastes, used tea leaves and sewage sludge for growing *Chlorella pyrenoidosa* Environmental Pollution, 23: 247 - 259.

Wood J.F., 1980. The preparation of water stable fish feeds. I. Methodology of feed preparation - a brief resume. Tropical Sciences, 22(4) 351 - 356.

Wood J.F, Capper B.S. and Nicolaides L, 1985. Preparation and evaluation of diets containing fish silage, cooked fish preserved with formic acid and low-temperature-dried fish meal as protein sources for Mirror Carp(*Cyprinus carpio*). Aquaculture, 44: 27 - 40.

Wood J.F. and Carter P.M, 1983. Investigations into the effects of processing on the retention of the carotnoid fractions of *Leucaena leucocephela* during storage, and the effects of processing on mimosine concentrations. Animal Feed Science and Technology, 9: 307 - 317.

Zohar G, Rappaport U. and Sarig S, 1985. The intensive culture of tilapia in concrete tanks. Bamidgeh 37(4): 103 - 111.